CONESTOGA HEADWATERS
PROJECT

PENNSYLVANIA

10-YEAR REPORT
1981-1991

RURAL CLEAN WATER
PROGRAM

U.S. DEPARTMENT OF AGRICULTURE
AGRICULTURAL STABILIZATION AND CONSERVATION SERVICE

CONESTOGA HEADWATERS PROJECT

Pennsylvania

RURAL CLEAN WATER PROGRAM

10-Year Report

1981 - 1991

Acknowledgment

This project received a tremendous amount of support from the various Federal, State and local agencies involved. Many thanks to the farmers who participated in the program and other individuals who made the project a success with their contributions. Valuable lessons were learned as a result of the project.

Agencies Involved:

Agricultural Stabilization and Conservation Service - USDA
Soil Conservation Service - USDA
U.S. Geological Survey - USDI
Pennsylvania Department of Environmental Resources
Environmental Protection Agency
Pennsylvania State University
Penn. State Extension Service
Lancaster County Conservation District
Eastern Lancaster County School District
Economic Research Service - USDA
Pennsylvania Department of Agriculture
PA State Association of Conservation Districts

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Comprehensive Monitoring and Evaluation Committee

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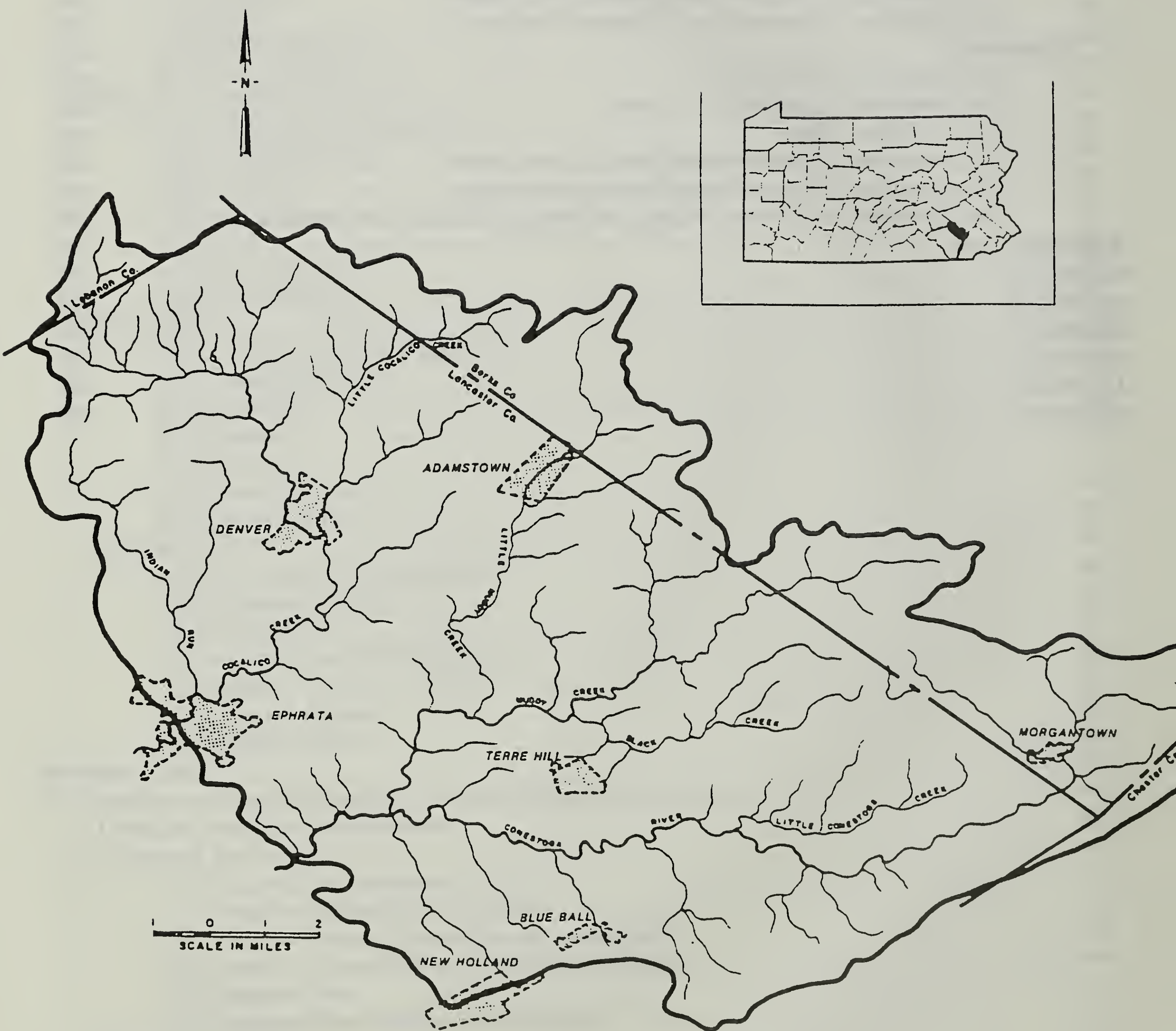

CONESTOGA HEADWATERS PROJECT AREA
LANCASTER CO., PA.

Authority

The Rural Clean Water Program is authorized by the Agriculture, Rural Development, and Related Agencies Appropriations Act of 1980, Public Law 96-108, November 9, 1979. Regulations 7CFR, Part 700.

Background

The Conestoga Headwaters RCWP Project was approved in July 1981 to accelerate the installation of best management practices (BMPs) on farms in the watershed to reduce agricultural pollutants that are degrading water quality in public and private water supplies. The project has been assigned a mission of determining the effects of agricultural BMPs on groundwater pollution abatement.

The surface and groundwaters of the Conestoga Headwaters area have protected uses as domestic water supplies for 175,000 people and as recreational fisheries. These uses have been seriously impaired by excessive levels of agricultural pollutants especially sediment, nitrate, and phosphorus. The goal of this project is to reduce pollutants to levels that are consistent with the water quality standards adopted for these waters by the Commonwealth of Pennsylvania.

The project area contains 110,000 acres with 63,000 acres of cropland. Livestock density exceeds 1.5 animal units per acre. Land is intensively cropped. Excess nutrients from agriculture were estimated to be 990,000 lbs. of nitrogen and 700,000 lbs. of phosphorus annually.

Project Strategy

Comprehensive monitoring has identified high nitrate levels in private wells, especially in areas with carbonate soils. RCWP cost-sharing contracting effort was concentrated in the carbonate soil areas that are being monitored. Farm visits by ASCS, SCS, and Lancaster County Conservation District personnel have created an interest in improved water quality management. The nutrient management BMP for manure and commercial fertilizer is making the most rapid impact on water quality improvement. During 1986 through 1991 nutrient management was implemented on 340 farms through a nutrient management office operated by the Cooperative Extension Service. RCWP contracting for Best Management Practice Implementation, non-cost-share BMP implementation, and Nutrient Management Planning in the project area complement each other in offering a complete water quality program delivery system.

Critical Area

High nitrate levels in private wells identified by the comprehensive monitoring have caused the Local Coordinating Committee to define the critical areas of the project. The priority one area has carbonate soil with a small watershed stream monitoring station. Nutrient management is the critical BMP needed. Priority two is other carbonate soil areas in the Conestoga Headwaters' watershed. Priority three is the non-carbonate soil portion of the watershed.

Project Accomplishments

RCWP contracted and cost-shared water quality Best Management Practices on 90 farms and 6,473 acres. The Soil Conservation Service supervised implementation of all BMPs except BMP15, Fertilizer Management. BMPs were installed without cost-sharing on approximately 115 farms with supervision by the Soil Conservation Service and/or Adult Vocational Agriculture Teachers. Cooperative Extension Nutrient Management personnel prepared nutrient management plans for 24,134 acres on 340 farms. Cumulative calculated efforts resulted in soil loss reduction of 110,000 tons, annual reduction of nitrogen by 1,293,142 lbs. and annual reduction of phosphorus (P_2O_5) by 566,576 lbs.

RCWP and the related activities in the Conestoga Headwaters area have substantially reduced pollution from agricultural sources. The program has provided knowledge and training for farmers,

technical personnel, researchers, agri-business, and program administrators in the management of agricultural water quality. The knowledge is being used by other water quality projects in Pennsylvania.

Water Quality Results

Water quality in the Conestoga headwaters basin was monitored at three scales - regional, small watershed, and field. At each scale surface- and ground-water quality of the basins were characterized, and except at the regional scale, the effects of agricultural BMPs on water quality were determined. In addition to water-quality data, associated geologic, precipitation, land-use, agricultural-activity, and soil data were collected. Qualitative and quantitative data analyses were based on the combination of all the data collected. Preliminary and final conclusions described below and based on site specific data, may be applicable to other sites with similar hydrogeologic and land-use settings.

Data from the 188-square-mile regional network documented that ground-water in carbonate areas is more susceptible to nitrate and herbicide contamination than ground-water in surrounding non- carbonate areas. Ground-water nitrate concentrations in about 50 percent of the samples from wells in agricultural, carbonate rock areas exceeded 10 mg/L as nitrogen (the U.S. Environmental Protection Agency's criterion for drinking water) throughout the year. Atrazine was detected in about 40 percent of water-well samples from agricultural, carbonate-rock areas throughout the year.

The small watershed study using a pre-BMP/post-BMP comparison, showed that the nutrient-management BMP, implemented on about 90 percent of the agricultural land of 1.42-square mile subbasin, did not significantly decrease the concentration of nitrate in base flow of the subbasin during the five-and-a-half year study period. However, additional qualitative analysis using a paired-watershed approach indicated that a decrease in base-flow nitrate concentrations may have occurred in the nutrient-management subbasin. Monitoring is being continued under another program.

After terracing at Field-Site 1 (22 acres), there was a significant reduction in suspended- sediment concentration in runoff, but no significant change in the total nitrogen or phosphorus concentrations in runoff. However, there was a significant increase in the nitrate concentration in runoff. Correspondingly, there was a significant increase in nitrate concentration in ground-water at 4 of the 6 monitored wells after terracing. Terracing did not result in change in runoff or recharge quantity at the site.

Nutrient-management at Field-Site 2 (48 acres) significantly reduced ground-water nitrate concentrations. Correspondingly, nitrate concentrations in runoff were significantly reduced after nutrient-management implementation, but no change occurred in total nitrogen or phosphorus concentrations in runoff from the site.

1.0 PROJECT FINDINGS AND RECOMMENDATIONS

- The Conestoga Headwaters did not meet the original National RCWP goal to "Solve the Water Quality Problem" by implementation of BMPs. However, nutrient reductions totaling 1,293,142 lbs. of nitrogen and 566,576 lbs. of P_2O_5 have been accomplished.
- Project applications should contain data to qualify and quantify the water quality problems. Water quality data needed to establish goals and set priorities for solving problems is necessary and should be available prior to approval of a project. Funding may be needed to obtain the data.
- The Conestoga Headwaters RCWP project indicates that all available knowledge applicable to solving agricultural non- point pollution problems may need to be used. In some instances even with the use of this knowledge there is a lack of total knowledge to solve the identified problem(s). Innovative BMPs and experimental practices may be site specific.
- Project BMP emphasis expanded to include nutrient management and erosion control on as many farms as possible without regard to RCWP contracts.
- Information and Education efforts by all available means of communication are essential to ensure farmer's understanding of how to solve water quality problems.
- USDA agencies, other federal agencies, state agencies, and others may need to pool their resources to successfully administer water quality programs. Coordination is required.
- Conestoga Headwaters water quality problems are attributed to high animal density (over 1.5 animal units per acre) and intensity of row crop production. Livestock density has increased substantially in the past twenty years due to integration of the livestock industry. Integrated agri-business needs to share in the cause of excess nutrients in this watershed. Local planners, educators, environmentalists, government officials and others should observe and interact with business actions that may adversely affect water quality and other environmental concerns.
- Nutrient Management (BMP15) was a very cost effective BMP to both government and to farmers in this project. It provided the opportunity for many producers to participate in RCWP water quality improvement with no financial investment. In most cases, farmers saved money because the nutrient plan reduced fertilizer input needs. However, where excess manure is produced, there is a definite cost to the farmer to find alternate land and/or sources to utilize the nutrients based on a sound nutrient plan. This BMP may not be as effective in areas with no or minimal excess nutrients.
- Comprehensive monitoring has provided the chemical data to guide farm planners with data to determine effective and efficient farm water quality plans.
- Monitoring and BMP evaluation may need to be utilized over an extended period (estimate 10 years or more) to effectively determine the reduction of nitrates in groundwater.
- The Conestoga Headwaters RCWP project provided a needed training experience for dozens of people in the several participating agencies. Several people who worked on this project are now working with similar projects in other states.

2.0 INTRODUCTION/PROJECT BACKGROUND

2.1 OVERVIEW OF THE RURAL CLEAN WATER PROGRAM

The Rural Clean Water Program (RCWP) is a federally-sponsored program designed to control agricultural nonpoint source (NPS) pollution in rural watersheds with the goal of improving water quality. Initiated in 1980, the RCWP was established as a 10- to 15-year experiment offering cost-sharing and technical assistance as incentives for voluntary implementation of Best Management Practices (BMPs).

The objectives of the RCWP are to:

- Achieve improved water quality in the approved project area in the most cost-effective manner possible in keeping with the provision of adequate supplies of food, fiber, and a quality environment.
- Assist agricultural land owners and operators to reduce agricultural NPS water pollutants and to improve water quality in rural areas to meet water quality standards or water quality goals; and
- Develop and test programs, policies, and procedures for the control of agricultural NPS pollution. With a total appropriation of 64 million, the RCWP has funded 21 watershed projects across the country.

These projects represent a wide range of pollution problems and impaired water uses. The RCWP projects were selected from state lists of priority watersheds developed during the Section 208 planning process under the 1972 Clean Water Act. Projects are located in Alabama, Delaware, Florida, Idaho, Illinois, Iowa, Kansas, Louisiana, Maryland, Massachusetts, Michigan, Minnesota, Nebraska, Oregon, Pennsylvania, South Dakota, Tennessee/Kentucky, Utah, Vermont, Virginia, and Wisconsin. While water quality monitoring has been performed in all 21 projects, five of the RCWP projects (Idaho, Illinois, Pennsylvania, South Dakota, and Vermont) were selected to receive additional funding for comprehensive monitoring and evaluation.

Each project involves both land treatment and water quality monitoring. Landowners were contracted to implement BMPs, with the length of the contract depending on the practice being implemented – typically three years minimum (e.g., conservation tillage) and ten years maximum (e.g., terraces, animal waste management systems). Most RCWP project contracts began in 1980-81 and ended in 1986, with project results currently being evaluated. The RCWP program will terminate in 1992; however, a few individual projects have been extended until 1995.

The RCWP is administered by the U.S. Department of Agriculture's Agricultural Stabilization and Conservation Service. Based on the principle of interagency cooperation and the existing federal/state/local partnership, the RCWP is also assisted by other federal agencies, including the Soil Conservation Service, Environmental Protection Agency, Extension Service, Forest Service, Agricultural Research Service, Economic Research Service, and Farmers Home Administration, as well as many state and local agencies.

Both direct water quality benefits and a wealth of experience in agricultural NPS pollution control have resulted from the RCWP. Results and lessons learned from RCWP projects constitute an important source of information for other federal and state NPS pollution control programs. The program has also helped to define research needs and has increased public awareness of this important water quality problem.

The following report constitutes a 10-year report on one of the 21 RCWP watershed projects. Each 10-year report describes the watershed project undertaken, monitoring conducted, results as of 1991, and recommendations. These 10-year reports, other project data, and on-site project evaluations will provide the basis for a final summary and evaluation of the entire RCWP to be prepared by the National Water Quality Evaluation Project (NWQEP) by the end of 1992. Finally, some of the projects that have been extended past 1991 may also publish addendum reports.

2.2 PROJECT BACKGROUND

2.2.1 Water Quality Problems and Impaired Water Uses

The major water quality problems in the project area are:

- Excessive nitrate and phosphorus originating from animal waste and excess use of commercial fertilizer.
- Pesticides from farms.
- Sediment from intense cropping.
- High coliform bacteria from animal waste. These impairments affect 132 miles of the Conestoga River and its tributaries in the project area.

Farmers in the Conestoga Headwaters produce 1,265,000 tons of manure each year and this manure when applied to fields releases large amounts of nitrates. Nitrates not used by the crops becomes a source of pollution in surface and underground water supplies, lowering the water quality.

Other possible sources of nitrate include waste water from septic tanks and sewage treatment plants, commercial fertilizers, and rain and snow. These sources are not considered to be critical.

A federal study released in 1983 revealed that southeastern Pennsylvania is a major polluter of nitrate and phosphorus to the Chesapeake Bay.

A study in the Conestoga Headwaters Project area conducted by the U.S. Geological Survey found that 50% of the private wells tested exceeded EPA standards for drinking because of nitrate and bacterial pollution.

The increase in animal units (Table 2-1) yields more manure and thus nutrients in excess of crop needs. These nutrients contaminate surface water and groundwater.

Table 2-1.--Lancaster County corn and livestock

[1 animal unit = 1,000 lbs. of live weight]

	1960	1970	1980	1990
Corn acreage	113,500	142,600	200,700	157,000
Animal units	200,216	305,798	571,992	--

The water of the Conestoga River and its tributaries, as well as ground water in the project area, are used primarily for domestic water supply and serve eight municipalities with a total population of approximately 175,000. Use of both surface water and groundwater for domestic water supply is seriously impaired. Swimming, fishing, and other recreational uses are impaired in surface waters.

2.2.2 Overview of Project

The Conestoga Headwaters experimental RCWP Project was approved in July 1981 as one of the 21 projects in the United States to be administered by Agricultural Stabilization and Conservation Service-USDA in agreement with the Administrator of EPA. The project was developed by Lancaster County, Pennsylvania State, and federal agriculture and water quality agencies. RCWP addresses agricultural pollution in the top priority watershed needing pollution abatement as identified by the Pennsylvania Section 208 Nonpoint Source Water Quality Plan. Major pollutants are nitrate and phosphorus primarily from animal waste. Sediment is also a pollutant.

Pollution control and abatement is accomplished through development of Water Quality Plans and the installation of Best Management Practices on individual farms. Best management practices apply to crop

and soil management and to livestock operations which produce manure. Control of soil erosion and applying nutrients to fields equal to crop nutrient needs are expected to solve most of the pollution problem.

The Project is one of five RCWP projects in the United States approved by the National RCWP Coordinating Committee for comprehensive monitoring of surface and ground water. The objective of the project is to accelerate the installation of Best Management Practices on farms in the watershed. These practices will reduce nutrients, sediment, bacteria, and pesticides that are degrading water quality in public and private water supplies. RCWP authorized cost-sharing contracts with farmers to implement those pollution abatement BMPs identified in a water quality improvement plan developed for farmers by the Soil Conservation Service. The project is locally administered by ASCS county committees and the Local RCWP Coordinating Committee.

The National RCWP Coordinating Committee assigned the Conestoga Headwaters Project a primary mission of determining the effects of agricultural BMPs on ground water pollution abatement. The water quality monitoring associated with this mission was managed by the Pennsylvania Department of Environmental Resources, Bureau of Water Quality, with hydrologic monitoring by the U.S. Geological Survey. The Pennsylvania State University assisted in planning monitoring strategy. The monitoring function was contracted to the Pennsylvania Department of Environmental Resources by the Pennsylvania RCWP Coordinating Committee.

Monitoring will determine current water quality and determine any change which may occur because of implementation of Best Management Practices.

Data obtained is summarized at the North Carolina State University by the Cooperative Extension Service.

2.2.3 Population, Climate, Physical Setting

Population - An estimated 40,000 people live within the project area. However, approximately 175,000 people and about 2,000 commercial industries downstream use the water that originates within the project area. Census projections indicate that the population in Lancaster County will be 440,000 by the year 2000. 1980 County Census of population reported 362,346.

The Conestoga Headwaters Rural Clean Water Project area is located in southeastern Pennsylvania, northeastern Lancaster County, with small portions of the project extending into Lebanon, Berks, and Chester Counties. The Conestoga River watershed consists of 477 square miles. The project area itself contains 188 square miles. (Map in front of this report.)

Farm population is approximately 75% of the plain religious sects. Farms are small and many are farmed with horses, mules, and steel wheeled equipment. The farmers accept technical assistance from USDA and Pennsylvania State agencies. They are reluctant to sign firm contracts and most do not accept government cost-sharing to implement Best Management Practices.

Climate - The growing season in Lancaster County averages 160 days with the last frost on April 30th and the first autumn frost on October 7th. In winter, the average temperature is 31 degrees F, and the average daily minimum temperature is 23 degrees F. In summer, the average temperature is 72 degrees F, and the average daily maximum temperature is 83 degrees F.

The total annual precipitation is 42 inches. Of this, 24 inches or 56%, usually occurs in April through September. The growing season for most crops is within this period.

Principal crops are corn, hay, wheat, tobacco and vegetables.

Physical Setting - The Conestoga Headwaters RCWP project is located in Northeastern Lancaster County, Pennsylvania. The area is 188 square miles, (110,000 acres) of which approximately 63,000 acres is cropland.

Cropland in the area consist of 27,000 acres of carbonate soils and 36,000 acres of shale, sandstone, conglomerate and diabase soils. Soils are moderate to well drained. Topography of cultivated cropland is

typically 1% to 10% slopes. Carbonate soils are intensively cropped and have high density dairy, livestock, and poultry farm operations.

2.2.4 Land Use and Existing Agricultural Practices

The Conestoga Project Area is part of the most intensely farmed area in Pennsylvania. Among non-irrigated counties, Lancaster County is a leading dollar volume agricultural producer in the United States. The major crops are listed in Table 2-2.

Approximately 63,000 acres or 57% of the 110,000 acre watershed is in cropland, 37% is in pasture, woodland, urban or other lands.

The average soil loss for the Conestoga River Watershed is 8.2 tons/acre/year. Sheet and rill erosion on cropland averages 9.2 tons/acre/year with 40 to 50 tons/acre/year erosion rates for individual fields being common. Cropland produces about 72% of the gross erosion in the county.

2.2.5 Project Justification

The Conestoga Headwaters was identified by the Pennsylvania Agriculture Plan, Section 208 of the Clean Water Act, as the number one priority watershed for agricultural pollution abatement.

High density livestock operations, maximum row crop production, high erosion rates, and high nutrient applications indicated a need for agricultural Best Management Practices that reduce pollution of water resources.

Table 2-2.--Statistics on the Conestoga Headwaters Rural Clean Water Program (1981)

Item	Quantity	Unit
Area of project	110,000	Acres
Number of farms	1,250	Farms
Number of cooperators (Consv. District)	387	Cooperators
Average acreage of farms larger than 15 acres	52	Acres/farm
Acres of planned farmland	21,256	Acres
Livestock farms (beef)	1,009	Farms
Dairy farms	445	Farms
Acres of corn grain	24,552	Acres
Acres of corn silage	11,682	Acres
Acres of hay	18,084	Acres
Acres of small grain	7,590	Acres
Acres of tobacco	2,310	Acres
Acres of potatoes	264	Acres
Acres of other crops	1,452	Acres
Dairy cows	22,058	Animals (39,542 cows)
Heifers	17,444	Animals
Breeding hogs	8,824	Animals (33,914 hogs)
Fattening hogs	25,090	Animals
Cattle for fattening	53,945	Animals
Poultry layers	1,465,101	Birds
Poultry broilers	1,997,324	Birds
Manure produced in project area	1,265,140	Tons/year
Manure produced in project area/farm	1,012	Tons/year
Manure spread rate for farmland	19.5	Tons/acre/year
Manure spread rate for cropland	24.3	Tons/acre/year

Public and private uses of water from the Conestoga River affect approximately 175,000 people in Lancaster County.

The Lancaster County Commissioners, the Lancaster County Conservation District, municipal water authorities, farm groups, state environmental agencies, and state and federal agricultural agencies agreed that agricultural pollution problems do exist.

The agencies also agreed that they can improve water quality in the Conestoga Headwaters by implementation of Agricultural Best Management Practices.

The Rural Clean Water Program provided a means to address agricultural pollution problems through Best Management Practice implementation, improved farmer and public education, and other experimental solutions.

USDA and others had the necessary expertise to implement the experimental aspects of RCWP.

Human and animal health are of concern due to high nitrate in drinking water on many farms and in rural water supplies.

2.3 PROJECT GOALS AND OBJECTIVES

2.3.1 Findings and Recommendations

FINDINGS: Initial project goals were based on data available in 1980 and 1981. Available data did not satisfactorily identify the water quality or the major water pollutants. Excessive agricultural nutrients applied to farmland are the major problem in the project.

- Erosion on farmland due to intense row crop production, land topography, soil erosion characteristics, and weather (rainfall) conditions are factors that influence delivery of pollutants to surface water and groundwater.
- Social and economic factors related to farmers influence the acceptability of RCWP contracting and the success of cost-sharing as a means to encourage implementation of pollution abatement water quality programs. Initial contracting goals in this project were unacceptable to farmers.

RECOMMENDATION: Water quality goals and objectives should be based on analytical data involving the chemical and biological analysis of surface water and groundwater, the cause of the water quality problem, the social structure of the community related to the problem cause and the acceptability of farmers to needed land use or management changes that may solve the problem, and the economic conditions applicable to solving the problem. This may include changes in land use, public cost- sharing, improved commodity income or a combination of economic factors.

RECOMMENDATION: An in-depth assessment of the problem, the cause, and possible solutions to the problem should be a priority function prior to determination of program goals and objectives. In some cases, current social and economic change may be solving the problem without public involvement. In other cases, the problem may be becoming more acute. In the Conestoga Headwaters Project, livestock density is increasing which is causing the excess nutrient problem to become more acute.

RECOMMENDATION: Program authority should permit changes in goals and objectives that may improve the success of the project.

2.3.2 Water Quality Goals and Objectives

FINAL GOALS: The final goals for the Conestoga Headwater Project of the RCWP are to cause water quality to meet standards of Chapter 93, Title 25 of the Pennsylvania Code which sets forth water quality standards for the waters of the Commonwealth. These standards are based upon designated uses for which these waters are to be protected. Nutrient standards applicable to unnamed tributaries in the Conestoga Watershed include the following:

- Nitrate plus Nitrite - Not to exceed 10.0 mg/1 as nitrogen
- Total Dissolved Solids - Not more than 500 mg/1 - monthly average, not more than 750 mg/1 at anytime.
- Ammonia Nitrogen - PA has a complex standard - Reference Chapter 93, Title 25 of the Pennsylvania Code.
- Other standards include alkalinity, chemical and biological guidelines. The RCWP objective was to meet the Pennsylvania standard.

INITIAL GOALS: The Conestoga Headwaters Project application proposed two stated water quality objectives. The first was to reduce nitrates, nitrites, phosphates, sediment, and pesticides in groundwater in the Conestoga Headwaters Project area. The second was to reduce turbidity in streams by controlling erosion. Some water supplies are affected by turbidity.

The local RCWP Coordinating Committee determined that 300 farms located adjacent to or near streams, covering 12,000 acres, applying water quality plans should improve water quality sufficiently to meet state water quality goals.

Adjustments and Refinements:

- In 1984 project personnel first defined Conestoga Headwaters Project water quality goals as those set forth by Chapter 93, Title 25 of the Pennsylvania Code.
- Project cost-sharing goals were reduced to 80 contracts with 6,000 acres.
- Ninety RCWP cost-sharing contracts were approved through September 1989 on approximately 6,500 acres.
- 1986 - Nutrient reductions of 750,000 lbs. of nitrogen and 375,000 lbs. of phosphorus should be accomplished by using BMPs on all possible farms through technical assistance for nutrient management and for erosion control.

2.3.3 Goals and Objectives for Implementation

FINAL GOALS: The final goals of RCWP implementation emphasized direct one-on-one contacts with farmers to implement water quality plans and RCWP contracts.

- The 1989 goal for RCWP contracts was 90 and the number of contracted acres was 6,500. Water quality plans were completed on 147 farms and 9,555 acres.
- Reduce nitrogen application by 750,000 pounds and reduce phosphorus by 375,000 pounds on 340 farms with 20,000 acres of cropland.
- Provide technical service for BMPs to all farmers in the project area.

INITIAL GOALS: The Conestoga Headwaters Project application goals for reducing nonpoint sources of pollution, included:

- To reduce nonpoint sources of pollution Conestoga Headwaters Project needed water quality plans and RCWP contracts on 300 critical farms. Three hundred contracts on 12,000 acres would cover 75% of the critical farms. The water quality plans were to reduce pollution as follows:
- Reduce soil erosion from 9 tons/acre/yr to 4 tons/acre/yr and thus reduce nitrogen loss by 480,000 lbs/year and phosphate loss by 120,000 lbs/year.
- Provide animal waste management with erosion control measures on 8,000 acres of row crops and 2,000 acres of small grains to reduce nitrogen loss by 13,000 lbs/year and phosphate loss by 2,800 lbs/year.
- Pesticide loss reduction of 50% on 12,000 acres by using erosion control Best Management Practices.

A 208 nonpoint pollution assessment of the Conestoga Headwaters Project by the Lancaster County Conservation District and the Department of Environmental Resources Bureau of Soil and Water Conservation identified high priority farms for RCWP contract application.

The following was the original implementation schedule:

- 1981 - Start-up including 25 Water Quality Plans with scheduled Best Management Practice cost-sharing (RCWP contracts).
- 1982 - 75 RCWP contracts.
- 1983 - 75 "contracts" and continue Best Management Practice installation.
- 1984- 1986 - 125 "contracts" and continue Best Management Practice installation.

Adjustment and Refinements:

- RCWP contracting for Best Management Practices with cost-sharing was not as acceptable to the farmers as the county officials expected. A study of water quality by comprehensive monitoring indicated high levels of nitrate and phosphorus from agricultural sources. Also a 1982 Lancaster Conservation District assessment indicated high nutrient levels from manure and fertilizer.
- Comprehensive monitoring identified high nitrates in private wells in carbonate soils of the Conestoga Headwaters Project area. In 1984 the RCWP Local Coordinating Committee determined to concentrate water quality planning on lands with carbonate soils. Within these carbonate lands a small watershed monitoring area on the Little Conestoga River was selected for primary concentration of RCWP BMPs.
- In 1986 the Conestoga Headwater Project opened a Nutrient Management Office with a goal to reduce nutrient applications of nitrogen and phosphorus on 20,000 acres.
- Farm visits showed that many farmers were reluctant to sign RCWP contracts so the final goal for total contracts was revised downward in 1984 from 300 to 80. In 1989 the goal was increased to 90 contracts with 6500 acres.
- By request of the local and state RCWP committees, the National Coordinating Committee approved the use of a nutrient management planning process for all farms on a voluntary basis. No RCWP contract was required for a nutrient management plan.
- In 1986 the Nutrient Management Program was implemented with two full-time cooperative extension nutrient planning technicians. Funding previously targeted for RCWP contracts was transferred to nutrient management. Nutrient management plans have been completed on 340 farms and over 24,000 acres in the project area.
- In 1987 contracting was extended through 1989.

2.3.4 Information and Education Goals and Objectives

FINAL GOALS: Educate farmers and the public concerning water quality standards and the agricultural management needed to maintain high quality water for human and livestock use.

INITIAL GOALS: To inform farmers and the public about the Rural Clean Water Program and to educate farmers on the ways and means to improve water quality related to agricultural production.

Adjustments and Refinements:

Emphasis changed from Rural Clean Water Program contracts to the management of farm enterprises in an environmentally acceptable manner. Nutrient management on farms became a primary I and E water quality goal.

2.3.5 Economic Evaluation Goals and Objectives

FINAL GOALS: Economic Research Service completed its work in 1986 with these final objectives:

- Estimate the costs and effectiveness of Best Management Practices in reducing delivery of nonpoint source pollutants.
- Estimate the economic impacts of RCWP on agriculture.
- Estimate the economic value of water quality improvements.
- Assess the social benefits and costs of the project, i.e. compare the total benefits and costs of water quality improvements.

The final economic evaluation was completed in 1986 and is included in Section 5.3.

INITIAL GOALS: Initially, Economic Research Service had included these three goals for the socioeconomic evaluation. They included:

- Evaluate the impacts of the implemented Best Management Practices on participating landowners and farmers and on local agriculture.
- Estimate off-site and community impacts of the RCWP program, with priority to the major off-site impacts resulting from changes in groundwater.
- Evaluate the cost- effectiveness of individual Best Management Practices with priority to those affecting groundwater quality and compare estimated project benefits and costs.

Adjustments and Refinements:

The Economic Research Service refined its socioeconomic evaluation goals from 1983 to 1986 making them more specific.

2.3.6 Water Quality Monitoring Goals and Objectives

FINAL GOALS: The final goal was to document changes in the quality and quantity of surface and ground waters in the project area. The specific objectives included:

- Quantify the transport of sediments, nutrients, and pesticides in surface waters.
- Quantify the movements of nitrate to groundwater aquifers.
- Investigate the transport of water-soluble pesticides to ground water.
- Measure the effectiveness of Best Management Practices in reducing nutrient pollution to surface water and groundwater.

INITIAL GOALS: The initial objectives as stated in the Conestoga Headwaters RCWP Plan of Work, 1982, were:

- Qualify and quantify nonpoint pollutants in the public and private water supplies originating in the Conestoga Headwaters.
- Technically identify critical area where pollutants are entering surface water and ground water.
- Determine ways and means of ground water pollution.
- Measure the effectiveness of individual Best Management Practices and systems of Best Management Practices in reducing and/or preventing surface water and ground water pollution.

Adjustments and Refinements:

The 1981 RCWP project application stated that PA DER and U.S. Geological Survey agreed to develop a plan for monitoring water quality in the Conestoga River Headwaters. Water quality monitoring personnel were asked to study effects of Best Management Practices on nonpoint sources in the Conestoga River above the City of Lancaster. This was to continue as long as feasible and needed.

Two field sites were selected to monitor ground and surface water. These sites will determine the effectiveness of individual BMPs in reducing agricultural non- point source pollution.

A small watershed site containing thirteen farms was designated to monitor the effectiveness of the Nutrient Management BMPs.

A second small watershed was monitored as a control area.

During the project monitoring program, procedures were evaluated and adjustments made to monitoring plans as determined to be needed by the Monitoring Technical Committee.

2.4 PROJECT DEVELOPMENT

2.4.1 Highlights of Project Development

The Conestoga Headwaters Project Area was identified using the National Clean Water Act, Section 208 process for assessing water pollution from non-point sources.

The Rural Clean Water Program authorized by the Agriculture, Rural Development, and related Agencies Appropriations Act of 1980, P.L. 96-108, provided federal support opportunity to treat the nonpoint source pollution problems attributed to agricultural operations.

Federal Agricultural Agencies in Lancaster County, the Lancaster County Conservation District, the Lancaster County Commissioners, and the Vocational Agriculture Departments in the project area, developed the project application with assistance from the USDA agencies and the State Bureaus of Soil and Water and Water Quality. Pennsylvania State University Extension and Agronomy personnel provided technical advice and support.

The State and Local Coordinating Committees applied for and were approved for Comprehensive Monitoring by the National RCWP Coordinating Committee.

PA State Department of Environmental Resources, U.S. Geological Survey and USDA Agencies had a common interest in agricultural non-point source pollution effects on water quality. The RCWP process provided a program to determine the severity of water quality problems, implement Best (Agricultural Water Quality) Management Practices on the land, and provide some financial assistance to measure the effectiveness of the implementation of Best Management Practices. State and federal agencies effectively pooled their resources to develop and implement the Comprehensive Monitoring portion of RCWP.

The PA Department of Environmental Resources Bureau of Water Quality provided funding and leadership to develop the monitoring plan. EPA provided funding to PA DER for the initial monitoring plan development. Pennsylvania State University, the USDA agencies, and U.S. Geological Survey provided assistance in developing the plan.

Institutional arrangements for implementing the plan were as follows:

- PA Department of Environmental Resources provided the monitoring management under contract with ASCS-USDA. U.S. Geological Survey sub-contracted with PA DER and provided the majority of the hydrologic monitoring in the field in cooperation with PA DER. USDA agencies served on a Comprehensive Monitoring Committee. RCWP water quality Best Management Practices were coordinated with monitoring activity, where necessary, by the Soil Conservation Service and the Local RCWP Coordinator.

- Partial funding for comprehensive monitoring was supplied by ASCS-USDA to PA DER by contract. PA DER provided additional funding. U.S. Geological Survey provided approximately one-half of the funding under a cost- sharing program with PA DER. Data collection and reporting of Comprehensive Monitoring activity was shared by PA DER and U.S. Geological Survey.

- Changes in the Project Plan - Soon after RCWP implementation started, it became apparent that RCWP goals could not be accomplished using only RCWP contracts. Nutrient management was needed on a majority of the farms to reduce nitrogen and phosphorus use. Many farms had

sufficient or excess nutrients from animal waste for crop production. These producers were also using substantial amounts of commercial fertilizer. The Local, State and National RCWP Coordinating Committees authorized a Nutrient Management Program for all farms without regard to RCWP contracts.

- Monitoring plans in the "small watershed area" were adjusted to monitor the effects of nutrient management.
- These adjustments were very effective in reducing nitrogen and phosphorous applications.

2.4.2 Summary of Annual Achievements

Ninety farmers participated in RCWP contracts with complete water quality plans.

Computed reduction of 1,293,142 lbs. of N and 566,576 lbs. of P (P2O5) is attributed to BMP installation.

Three hundred and forty farms received and implemented Nutrient Management Plans (BMP15). Annual calculated reduction of 523,000 lbs. of nitrogen and 151,000 lbs. of phosphorus was accomplished by Nutrient Management Plans.

Detailed descriptions of annual achievements are in sections 3.2.2, 3.3, 4.2 and 5.3.2.

2.5 CHANGES IN LAND USE PATTERNS AND WATER RESOURCE MANAGEMENT THROUGHOUT THE PROJECT PERIOD

2.5.1 Impact and Effect of Federal Programs (PIK, Dairy Buy-out, CRP, Other)

These programs had very minimal effect on water quality in the project area. Participation in Federal government programs is negligible.

2.5.2 Impact of Cropping and Chemical Use Changes

Cropping patterns have changed very little in the project area. Row crop production may have increased slightly. Commercial fertilizer use was substantially reduced in the area due to RCWP.

Information and education because of RCWP and related programs are having a very desirable impact on reducing nutrient applications. A local private agronomic service representative recently reported in the PA Farmer Magazine that commercial nitrogen use in this county has been reduced by 30% since 1980.

Herbicide use is declining slightly due to Integrated Crop Management and improved education. Commercial applicators are used extensively in the project area. These operators are state licensed and required to pass prescribed pesticide use testing.

2.5.3 Review of Changes in Population, Construction, and Other Factors

Actual demographic data is not available, but the population is definitely increasing. New housing is noted in nearly all of the project area.

2.5.4 Impact and Effect of RCWP

RCWP had a very positive water quality benefit in educating agricultural leaders, businesses, and farmers concerning current water quality, causes of water quality degradation, and ways to reduce water quality problems. RCWP survey of farm management practices indicated an extremely high evidence of excess nutrient application on farms. This information stimulated local and statewide agricultural leadership to rethink many agronomic recommendations. The Pennsylvania State University cooperated in updating soil testing and manure testing procedures and the related agronomic recommendations. Nutrients in animal waste have been evaluated and book values made available for those farmers that may not use manure nutrient testing. Nutrient management is providing a tremendous water quality benefit in Pennsylvania. Several crop management associations have been formed. Private agronomists are using nutrient management planning. The PA Chesapeake Bay Program and others are using a nutrient management program patterned after the Conestoga Headwaters RCWP Nutrient Management effort.

3.0 IMPLEMENTATION RESULTS

3.1 FINDINGS AND RECOMMENDATIONS

FINDINGS: Contracting RCWP with firm long-term contracts was not well accepted by farmers in this project. Many of them are of plain religious sects and generally do not accept cost-sharing.

- Technical service and educational efforts were well accepted by farmers and the public.
- Water quality is a concern of most people in the project area. RCWP has created a public awareness of water quality that did not exist when the project started.
- Institutional arrangements of RCWP worked well in the Conestoga Headwaters Project. Agencies gave timely service to the public need.
- The goal of RCWP, "to solve the water quality problem," was not accomplished in the project. However nitrogen and phosphorus applied to agricultural land was reduced by 523,000 lbs and 151,000 lbs., respectively, by nutrient management alone. Benefits from erosion control Best Management Practices are in addition to nutrient management. Section 3.2.2 identifies program accomplishments.

RECOMMENDATION: Water quality Best Management Practices could be available for cost-sharing without whole farm contracts.

RECOMMENDATION: Water quality technical service may be made available on a watershed or project basis without regard to contracting.

RECOMMENDATION: Technical service funding should be available to the agency or agencies that may best be able to supply needed services.

RECOMMENDATION: A USDA standard system for evaluating the water quality benefits of erosion control practices is recommended.

RECOMMENDATION: In this project, the CREAMS model was used. CREAMS measures the benefit of erosion control practices in the delivery of nutrients to surface water at the field edge. If nutrients are not delivered with runoff or sediment, it appears that they remain as a pollutant available to groundwater.

3.2 CRITICAL AREA TREATMENT

3.2.1 Definition of Critical Area

The critical areas for nonpoint source agricultural pollution have been identified as:

- Those farms adjacent to the major streams within the Conestoga Headwaters area.
- Those farms adjacent to small tributaries within the watershed.
- Livestock farms having an animal unit density greater than 1.5 animal units per acre.
- Those farms using high rates of commercially supplied nutrients and pesticides on all or most of their land.
- Farmland having an annual erosion rate twice the soil loss tolerance (T).

The critical pollution sources include:

- Animal waste.
- Barnyard run-off.
- High rates of commercial fertilizer and/or pesticides applied to cropland.

- Inadequate erosion control on farmland.
- Pollutants to be reduced are nitrate, nitrite, phosphorus, sediment, coliform bacteria, and pesticides.

Early comprehensive monitoring identified excessive nitrate concentrations in private wells, especially in areas with carbonate soils. This caused the Local Coordinating Committee to redefine the critical areas of the project. The priority one area had carbonate soil with a small watershed monitoring station on the Little Conestoga Creek. Priority two involved other carbonate soil areas in the project area. Priority three was the noncarbonate soil portion of the watershed.

3.2.2 Accomplishments

During the course of the project, the Conestoga Headwater Project Coordinator, representatives of the Soil Conservation Service, Eastern Lancaster School Adult Farmer representatives, the Lancaster County Conservation District, and Cooperative Extension Service made personal visits to 1,040 farmers in the Conestoga Headwaters. Most of the farmers are of plain religious faith and are not accustomed to government contracts. However, the people are quite willing to discuss water quality and indicated a need to implement changes in farm management to improve water quality. Non-contracted Best Management Practices applied exceed the contracted Best Management Practices applied in the Conestoga Headwaters Project area (see Tables 3-1 and 3-2).

3.3 BEST MANAGEMENT PRACTICE IMPLEMENTATION

3.3.1 Description of Each Best Management Practice and the Problem It Addressed

Refer to Table 3-3.

3.3.2 Acres Served by Each BMP and BMP Units Installed or Implemented Under RCWP

Refer to Table 3-2.

3.3.3 Number and Proportion of Project Area Producers Implementing Each BMP

Refer to Table 3-2.

3.3.4 Discontinued Best Management Practices

Few Best Management Practices were discontinued. Some no-til practices were changed to conservation tillage.

3.3.5 Changes in Best Management Practice Emphasis

RCWP original BMP emphasis was in using erosion control as a means to reduce sediment in streams and reducing the nutrients associated with sediment.

Early in the project, a farm management survey conducted by the Lancaster County Conservation District indicated extremely high rates of nitrogen applications on many farms. Nitrogen from manure plus commercial fertilizer was in excess of annual crop needs.

Monitoring efforts in the project have identified ground water nutrient pollution in excess of EPA standards in the carbonate soil areas.

The initial nutrient management plans (1982-1985) on approximately 6,900 acres were based on standard Pennsylvania State University soil testing procedure. Manure supplied nutrients were given limited consideration in crop nutrient recommendations. RCWP nutrient budgets were developed to match nutrient applications to the expected crop needs. Many farms had adequate or excessive nutrients from manure to meet the need. Experimental soil testing to depths of four feet identified high residual carry overs of nitrogen after crop harvest. This condition is prevalent on high density livestock farms (2 or more animal

Table 3-1.--Best Management Practices, units, and nutrient reductions, Conestoga Headwaters RCWP Project

[Calculated nutrient reduction attributed to BMPs installed. CREAMS model was used to compute nutrient reductions by BMP in 1984. 1984 data was used to compute nutrient reductions for BMPs installed during the entire project period, except for BMP 15.]

Best Management Practice	Unit	Nitrogen reduction	Phosphorus reduction (P_2O_5)
BMP 1 Permanent vegetative cover	Acre 208	5,824	3,058
BMP 2 Animal waste management system	No. 69	–	–
BMP 3 Stripcropping systems	Acre 2,913	75,039	42,879
BMP 4 Terrace system	Mile 62	82,026	48,608
BMP 5 Diversion system	Mile 8	17,520	7,380
BMP 6 Grazing land protection system	No. 4	–	–
BMP 7 Waterway system	Mile 27	105,840	58,590
BMP 8 Cropland protective system	Mile 3,346	38,144	18,068
BMP 9 Conservation tillage systems	Acre 12,515	446,035	236,533
BMP 10 Stream protection system	No. 5	–	–
BMP 11 Permanent vegetative cover on critical areas	Acre 1	–	–
BMP 12 Sediment retention, erosion, or water control structures	No. 3	–	–
BMP 15 Fertilizer management	Acre 24,134	522,714	151,460
BMP 16 Pesticide management	Acre	–	–
Total nutrient reductions	* lbs.	1,293,142	566,576
Soil loss reduction	110,000 tons		

* Calculated nitrogen reduction exceeds the project estimated excess nitrogen application, which was 990,000 lb.

units per acre) and farms using high commercial nitrogen applications. Nutrient management efforts were concentrated on these farms. Nutrient management planning recommendations are continuously being fine-tuned to reflect the latest research. There are now 24,500 acres in the project area using guidelines developed during RCWP. These same nutrient management guidelines have been adopted statewide. Nutrient management is a very necessary BMP when excess nutrients are the pollutants to be reduced.

Barnyard run-off control was part of an animal waste facility and was addressed as such. All local agencies now recognize barnyard control as a Best Management Practice component of Animal Waste Management.

3.4 CONTRACT MODIFICATIONS AND VIOLATIONS

3.4.1 Total Number of Contracts

There were 90 RCWP contracts on 6,473 acres. Water quality plans were written on 9,555 acres. Many applicants were interested in improving water quality and securing the advice of technical people without RCWP cost-sharing. The project area has a high number of conservative farmers who do not wish to receive

Table 3-2.--Acres or units treated or served by each BMP implemented under RCWP, total cost-shared and non-RCWP BMP outlays in the Conestoga Headwaters Project

[N.A., not available]

BMP#	Goal	Units	Total installed BMPs Unit	Cost Shared BMPs Units	Cost Shared BMPs C/S Value	Non-cost shared BMPs Units	Non-cost shared BMPs Cost
1	800	AC	208	30.0	1,470	178	8,900
2	80	NO	69	40.0	360,355	30	450,000
3	2,200	AC	2,913	234.0	1,6082,747	29,310	
4	93	MI	62	37.6	353,497	27.7	408,049
5	9	MI	8	3.3	17,787	4.7	77,178
6	30	NO	4	2	1,694	2	1,236
7	28	MI	27	7.4	48,579	20.4	379,146
8	2,500	AC	3,346	696	4,1922,650	15,976	
9	12,000	AC	12,515	6,409	06,106	73,272	
10	60	NO	5	2	1,058	3	1,500
11	64	AC	1	0	0	0	0
12	30	NO	3	1	3,712	2	7,000
14	30	AC	3	0	0	3	225
15	7,200	AC	24,500	24,134	0	374	N.A.
16	7,200	AC	6,900	3,879	0	3,021	N.A.
COST SHARE VALUE			$793,952				
FARMERS NET COST			$712,086				
TOTAL COST			$1,506,038	*$1,451,792 EST			

* Includes practices reported by Eastern Lancaster County School District Ag Instructors and non cost shared BMPs serviced by the Soil Conservation Service

cost-sharing, but do accept technical service. Technical service was provided to install more Best Management Practices on non-contract farms than on RCWP contract farms. (See figs. 3-1 and 3-2)

3.4.2 Contract Cancellations and Modifications

Three contracts were cancelled. One sold out after completing a surface water control practice. The new owner followed the water quality plan but did not want cost-share funds. One farmer died before completing any of the cost-shared Best Management Practices. The farm involving the third cancelled contract was sold. The new landowner took over the existing contract and completed the work.

Many contracts were modified or the Best Management Practices were rescheduled. The modifications of contracts were due mainly to changes in rotations and farm changes from dairy to hogs or vice-versa. In some cases acreage in cultivated crops increased, requiring more surface water control, while others went to more hay and small grain and eliminated the need for certain Best Management Practices. The use of earthen manure pits was abandoned due to the limestone geology where sink holes are common or due to high water tables or due to closeness to bedrock. Others were modified as a result of the added interest in barnyard runoff control. In a few cases funds were added to repair the practices that were destroyed by severe storms before vegetation was fully established.

Rescheduling was due to lack of funds on the landowner's part. Adverse weather conditions occasionally prevented establishment of Best Management Practices on schedule. When farm economics were favorable many clients completed their water quality contracts ahead of schedule.

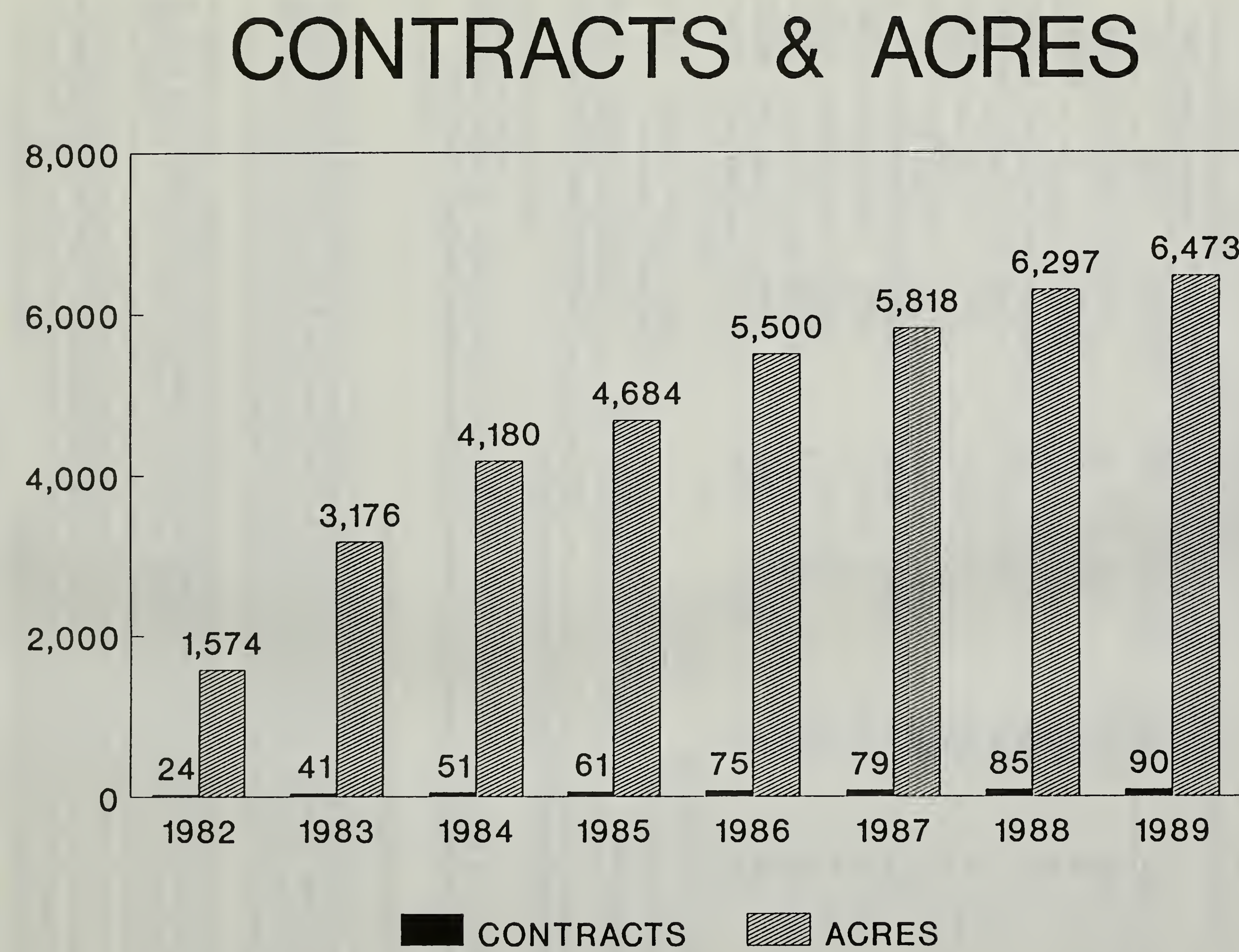

Figure 3-1.-- Number of contracts and acres under contract.

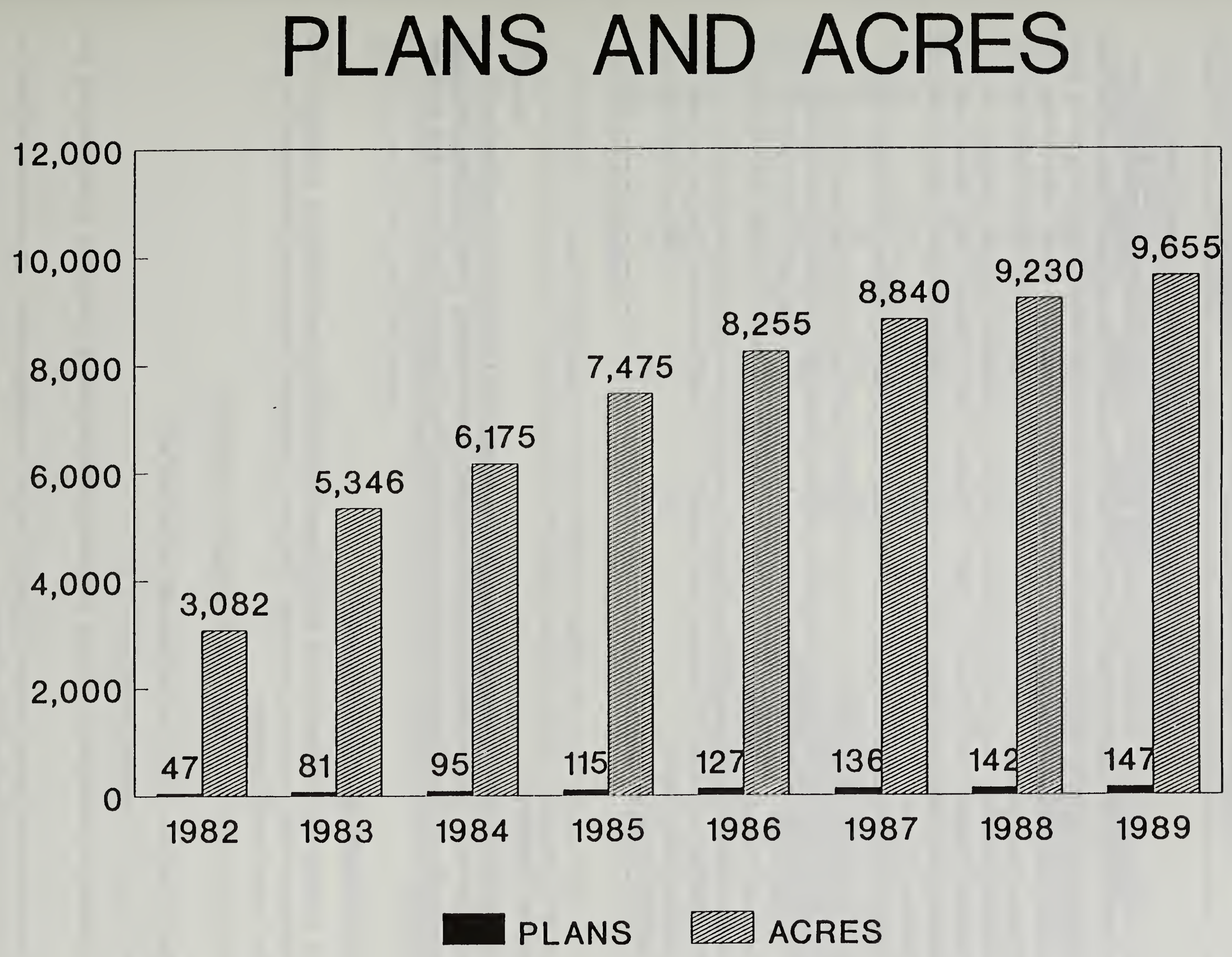

Figure 3-2.-- Number of water-quality plans and acres covered under the plans.

Table 3-3.—Conestoga Headwaters BMPs and the problem addressed

[S, Significant; M, Moderate; A, Addressed; N, Negligible]

		Soil erosion			
		Reduction		Water quality	
BMP#	BMP Name	sheet & rill	Gully	Ground	Surface
1	Permanent Vegetative Cover	S	M	M	S
2	Animal Waste Management System	N	N	S	S
3	Stripcropping Systems	S	M	M	S
4	Terrace System	S	S	N	S
5	Diversion System	S	S	N	S
6	Grazing Land Protection System	S	N	S	S
7	Waterway System	N	S	N	M
8	Cropland Protective System	M	N	S	M
9	Conservation Tillage System	M	N	N	M
10	Stream Protection System	M	N	N	S
11	Permanent Vegetative Cover on Critical Areas	S	M	N	M
12	Sediment Retention, Erosion or Water Control Structures	N	S	M	S
14	Tree Planting	S	M	S	S
15	Fertilizer Management	N	N	S	S
16	Pesticide Management	N	N	S	S

3.4.3 Contract Violations

Practices installed are for the most part being properly maintained. On one of the completed contracts the new landowner took out the contour strips and replaced them with field strips. The landowner had fulfilled his obligation and erosion was satisfactorily controlled. The Conestoga Headwaters had no major contract violations.

3.5 IMPACTS OF OTHER FEDERAL PROGRAMS

The new wetlands bill is affecting Best Management Practice #6 by preventing the installation of 2 spring developments which are now in wetlands. The Dairy Termination Program also eliminated the need for one animal waste storage structure.

The Conservation Reserve Program did not impact on this project.

3.6 IMPACTS OF STATE AND LOCAL PROGRAMS/REGULATIONS

No state or local laws were in conflict with RCWP.

RCWP created an awareness of nutrient pollution problems among municipal authorities and the public.

Local government ordinances are now in effect in several townships which require nutrient plans for handling manure from animal waste structures.

A nutrient management bill is pending in the Pennsylvania Legislature.

Pennsylvania Department of Environmental Resources 'clean streams' law is applicable to severe pollution problems.

Pennsylvania Department of Environmental Resources has a manure handling manual that is available to help Pennsylvania farmers manage nutrients resulting from animal waste.

3.7 TECHNICAL ASSISTANCE

3.7.1 Overall Assistance Provided to RCWP Producer Participants

Soil Conservation Service (SCS) technical assistance in the area of water quality planning and application of Best Management Practices was available to all farm operators. RCWP Water Quality Plans were developed, RCWP contracts were supervised, and annual progress reviews were completed by the Soil Conservation Service. Technical expertise from the SCS, the Cooperative Extension Service, Penn State Ag Experiment Station and others assisted the Monitoring Committee.

The Lancaster County Conservation District provided technical assistance for no-til cropping and provided no-til corn planters. The Lancaster County Conservation District helped Agricultural Stabilization and Conservation Service and Soil Conservation Service in making farmer contacts.

3.7.2 Types and Amount of Assistance Provided to Producers Implementing Each BMP

The Soil Conservation Service planned 90 RCWP contracts, supervised the Best Management Practices implementation and designed and certified all Best Management Practices. The Soil Conservation Service also designed Best Management Practices and supervised implementation on project area farms without RCWP contracts. Table 3-2 shows the types and amounts of BMPs installed.

The Cooperative Extension Service Nutrient Management Office wrote nutrient management plans for 340 farms in the project area (see Table 4-1). Planners took manure and soil tests at each one of these farms as part of the planning.

3.7.3 Lessons Learned

Flexibility of Best Management Practice selection needs to be a local function. Design and implementation schedule for Best Management Practices needs to suit the producers' finances and social attitudes.

Technical assistance needs to be available to all land operators to accomplish the maximum water quality improvement.

Expertise in delivering technical assistance to farmers may be shared by agencies who have personnel with the needed technical disciplines.

4.0 PROJECT INFORMATION AND EDUCATION ACTIVITIES

4.1 FINDINGS AND RECOMMENDATIONS

FINDINGS: Individual contact with farmers was instrumental in project area farmers desire for conservation plans. The individual farmer contacts by the Soil Conservation Service, Agricultural Stabilization and Conservation Service, Eastern Lancaster County Adult Farmer Program, Lancaster County Conservation District and Cooperative Extension Service Personnel influenced many farmers to implement water quality Best Management Practices.

- Multiagency involvement in information dissemination worked well in this project. Good coordination was provided by the County Extension Service and the RCWP project coordinator.
- Information and education efforts appeared to produce Best Management Practices on more farms than the RCWP contracting with cost-sharing. Cost-sharing and educational activities complement each other and offer farmers a choice that may satisfy individual social needs as well as economic needs.

RECOMMENDATIONS: For projects such as this where many farmers have no contact with the mass media, individual contacts are necessary to disseminate information.

- All information and educational delivery systems available should be used. Mass media, workshops, demonstrations, individual contact, related educational meetings, etc. are effective in promoting water quality improvement.
- Educational programs need to be implemented by people and organizations that farmers know and trust.
- Educators need to understand and respect the cultural, religious, and social customs of the clientele.

4.2 COOPERATIVE EXTENSION SERVICES ACTIVITIES

Penn State Cooperative Extension was the agency with primary responsibility for education and information. In January of 1986, Penn State hired two full-time extension agents to staff a nutrient management office and develop nutrient management plans for farmers in the Upper Conestoga Watershed. The goals of this phase of the project were:

- Reduce nitrogen applications by 750,000 lbs. on 20,000 acres.
- Reduce phosphorus applications by 375,000 lbs. on 20,000 acres.
- Encourage the adoption of other Best Management Practices (BMPs).
- Encourage the development of a crop management association to continue nutrient management and integrated pest management after the project is completed.

The primary strategy involved providing farmers with an individual nutrient management plan. This was accomplished by providing an analysis of current farm management and developing a nutrient plan that matched nutrient application to planned crop needs. Soil and manure was tested for participating farmers. The cost of soil and manure testing was paid for from Rural Clean Water Program (RCWP) funds. These test results along with manure production calculations were utilized in making the fertilizer recommendations for specific crops produced on each farm.

Voluntary nutrient management plans for all farmers have encouraged implementing best management practices by the conservative Amish and Mennonite farmer. Many of these farmers, who comprise 75% of the farmers in the watershed, have only recently accepted government assistance. Most farmers were willing to have an individual nutrient management plan completed for their farms. Farmers learned of the nutrient management program primarily through individual visits by project staff. An effort

was made to target farmers with significant amounts of livestock. Most of the soil testing was done in the fall and early spring. Over winter, manure and fertilizer recommendations were taken to the farmers and explained to them individually. Each extension agent was able to work with approximately 40 farmers per year. Surveys of participating farms were conducted in 1987 and 1989 to determine the amount of actual fertilizer reduction. The data was collected by conducting personal interviews with the farmers. Forty- eight (48) farmers were interviewed in 1987 and 78 farmers were included in a 1989 survey. A group of farmers who did not receive nutrient management plans were also interviewed as a control group. A separate control group was used with each survey. These surveys helped to evaluate the effectiveness of individual nutrient management planning. Table 4-2 shows the amount of excess nutrients in the watershed and the amount of recommended reductions. The Table indicates the estimated amount of actual reductions based on a 1989 survey. The results of this survey highlight the effectiveness of education. Farmers actually reduced their fertilizer use by 79% of the recommended nitrogen and 45% of the recommended phosphorus. This represents an increase in reductions from a 1987 survey which found that farmers had reduced 55% of the recommended nitrogen and 33% of the recommended phosphorus. As farmers develop more confidence in nutrient management plans, actual compliance should increase. A follow-up study is being conducted by the Penn State Agriculture Education Department to further quantify the effectiveness of individual visits for water quality instruction.

Test plots comparing different rates of fertilizer on corn were conducted each year on 12 to 18 farms. These plots were generally conducted on farms where the nutrient management plan called for little or no commercial fertilizer. The plots were able to show farmers that nutrients from manure may meet the crop nutrient need. Where no additional fertilizer was applied, the yields were not significantly different than the treatments receiving fertilizer. In addition to the benefits these plots provided to the farmers, they also enabled Penn State University agronomists to fine-tune their nitrogen recommendations.

Fifty-one test plots were conducted during the five growing seasons the Nutrient Management Office was open. Twenty-eight of the plots compared different rates of nitrogen fertilizer on fields receiving manure. Only one of the plots showed a statistically significant yield increase from additional nitrogen.

Table 4-1.--Total Nutrient Reduction Recommendations for 340 Nutrient Management Plans

Reductions for 1/86 through 4/91	Acres	Lbs. Nitrogen	Lbs. Phosphorus	Lbs. Potash
Total reduction per acre	24,134	-661,663	-336,577	281,488
		-27	-14	-12
Corn per acre	15,075	-625,668	-217,363	-185,445
		-42	-14	-12
Hay per acre	5,720	-15,362	-86,898	-66,971
		-3	-15	-12
Other crops per acre	3,339	-20,639	-32,316	-29,072
		-6	-10	-9

Table 4-2.--1989 Nutrient Management Survey

	Total watershed nutrient excess (estimated)	Recommended reduction	Actual reduction based on survey
Nitrogen	990,000 lbs.	661,663 lbs.	522,714 lbs.
Dollar value of nitrogen at $.25/lb	$247,500	$165,416	$130,679
Phosphorus	700,000 lbs.	336,577 lbs.	151, 460 lbs.
Dollar value of phosphorus at $.30/lb	$175,000	$100,973	$68,157

Twenty-three of the plots compared starter fertilizer, starter fertilizer containing zinc, and no starter. Three of these plots showed a significant yield increase with starter fertilizer.

Penn State University agronomists also conducted nitrogen response plots on RCWP farms. Nutrient management staff assisted in data collection from the farmers. Agronomists used these plots to develop a nitrogen soil test and fine-tune nitrogen fertilizer recommendations for corn. As a result of the early test plots and nutrient management plans, Penn State changed their nitrogen recommendations for corn fields which had a history of manure application. The new recommendations gave credit for the releases of nitrogen from previous and current manure applications. These recommendations first appeared in the 1988 Penn State Agronomy Guide. This change resulted in significant reductions of nitrogen fertilizer use throughout the state.

The Farm Nutrient Management Worksheet computer software developed by Dr. Doug Beegle and Phil Durst, was field tested in the Nutrient Management Office. A revised version of the Farm Nutrient Management Worksheet software is now in use. A Pre-Sidedress Nitrogen Soil Test developed by Dr. Richard Fox, was field tested with the general public in 1989 and 1990. The purpose of the test is to determine the need for additional nitrogen by the current growing crop. This test was used extensively in the Upper Conestoga Watershed. The soil test was designed to measure soil nitrate levels in mid-June in soils with an organic source of nitrogen such as manure or legumes. Extension agents performed the test in their office. This enabled the farmer to receive the test results within 24 hours of when the test was taken. If additional nitrogen is needed, it can be timely applied during the growing period for the crop. The test was used on fields where the nutrient management plan called for little or no nitrogen. The RCWP nutrient management office provided an excellent laboratory for this test because of the large number of livestock farmers who had eliminated commercial nitrogen fertilizer applications. This test prevented many unnecessary "insurance" fertilizer applications. During the 1989 and 1990 growing seasons the test was used on approximately 300 fields.

Each February, a meeting was held for area fertilizer dealers. This meeting was designed to inform area fertilizer dealers of the progress of the Upper Conestoga RCWP and to keep them informed of the latest recommendations in nutrient management. Other topics of this annual meeting included pesticide safety and business opportunities in nutrient management. The meeting facilitated communication with the industry which lost sales due to good nutrient management. Farmers rely heavily on fertilizer dealers for their advice on crop production and it was encouraging to see their support of water quality programs.

Nutrient management extension personnel hosted two to three tours and spoke at many farmer meetings each year. Staff also assisted in training nutrient management staff in a Maryland Department of Agriculture project that was patterned after the Conestoga Headwaters Project. Feature stories in several local newspapers made the community aware of the nutrient management office and its objectives. In addition, articles based on the Upper Conestoga nutrient management experience appeared in national publications such as "Land and Water," "Farm Journal," and "Successful Farming."

Manure tests are a critical component of a nutrient management plan. Prior to the RCWP program very little manure testing had been done by farmers. Manure testing was widely promoted in magazine articles and local crop meetings. Since January of 1986, the RCWP Nutrient Management Office has taken over 500 manure samples. While there is a significant amount of variance among samples, the averages have consistently been 5-15% higher than published book values. These averages are in Table 4-3.

Manure values for solid manure are based on lbs/ton. Liquid manure values are expressed as lbs/100 gal.

Manure from animals on bedded packs varied widely from farm to farm. To determine the extent of the variability in manure nutrient values, manure samples were taken on two farms at regular intervals. It was found that manure nutrient values varied by as much as 150% within the same pen of steers over the life of the animals. Manure samples taken from the same pen on the same day varied less than 10%. Therefore, it was felt that manure sampling gave a fairly good picture of the manure nutrient value on any given day. However, in the case of bedded pack manure, average values may provide a better view of the total available manure nutrients.

Table 4-3.--Averages of Manure Test Results

Manure Type	# of Samples	% Moisture	Lbs/Gal.	N	P205	K20
Dairy (Solid)	123	82.2		10.8	5.8	9.2
Dairy (Liquid)	61		8.44	3.3	1.7	2.9
Dairy Heifers	61	75.8		13.1	7.0	14.5
Beef	172	75.1		14.1	7.4	13.1
Swine (Fattening)	29		8.43	6.0	4.4	2.5
Swine (Farrowing)	42		8.40	3.0	1.8	1.7
Swine (Solid)	10	74.3		21.6	18.4	15.2
Poultry (Layers)	11	57.7		37.1	46.0	23.8
Poultry (Broilers)	14	31.4		59.8	54.3	34.0
Turkeys	7	42.4		49.3	45.5	30.0

Newsletters were sent out twice a year to participating farmers. Test plot results and other information concerning water quality around the farm was included. A list of farmers who had excess manure to sell or give away, as well as a list of farmers who are willing to accept or purchase manure, was included in the spring newsletter. This list provided opportunity to market some of the excess manure on farms that did not have livestock and needed to purchase additional commercial fertilizer. Farmers who received manure were then able to reduce their fertilizer applications. In addition to spreading the manure over a larger area, this program created a total watershed reduction of nutrients. The manure buy/sell list was used as a model for a larger multi-county listing that was developed as part of the Chesapeake Bay Program.

County extension staff held approximately 10 educational meetings each year (i.e. Crops Day, Dairy Day, Poultry Day, etc.) at which nutrient management and water quality issues were discussed. Radio programs and newspaper columns often emphasized nutrient management and water quality. As a result of the RCWP project, Lancaster County Cooperative Extension has established a permanent nutrient management/water quality position to continue the educational effort started in the RCWP Conestoga Headwaters Project.

RCWP funds combined with Chesapeake Bay funds were used by Penn State's Department of Agricultural Engineering to develop water quality education materials. These materials included fact sheets, slide shows, exhibits and videotapes. Ag Engineering staff participated in several water quality clinics including one in Lancaster County. A survey of participants at that clinic found that 30% of the respondents had been unaware of the sources of nitrate.

4.3 ASCS ACTIVITIES

ASCS hired one part-time employee to work in the RCWP project area as a local coordinator. His responsibilities included making farm visits to encourage new contracts for water quality Best Management Practices, revisiting farmers with existing contracts, and collecting farm management data for the small watershed monitoring. These visits encouraged farmers to adopt additional water quality Best Management Practices as well as encourage proper maintenance of existing Best Management Practices.

Agricultural Stabilization and Conservation Service produced two special pamphlets, one special RCWP Newsletter, periodic county newsletters, an RCWP poster and assisted with farm tours.

4.4 SOIL CONSERVATION SERVICE ACTIVITIES

Soil Conservation Service worked on RCWP contract and non-contract farms to explain Best Management Practices to farmers and provided technical service for Best Management Practices being implemented.

The Soil Conservation Service conducted several farm tours for Pennsylvania and out-of-state Soil Conservation Service personnel. The Soil Conservation Service participated in most tours hosted within the Conestoga Headwaters Project.

4.5 WATER QUALITY AGENCIES ACTIVITIES

The U.S. Geological Survey and the Pennsylvania Department of Environmental Resources were responsible for water quality monitoring. They planned monitoring strategy, collected and analyzed water quality data, and published water quality findings.

Numerous tours of the monitoring sites were conducted to explain water quality monitoring. Tours included diverse groups such as farmers, college students, elementary school students, geologists, government officials, and others. Results of the RCWP monitoring were presented at 36 educational and professional meetings in the RCWP watershed and throughout the country. The water quality team served as a resource for 10 newspaper articles and a television program. Five technical papers based on the findings of the RCWP program were published. Additional research papers are being prepared. All published and planned water-quality reports are listed in Appendix F.

4.6 LOCAL COORDINATING COMMITTEES/STATE COORDINATING COMMITTEE ACTIVITIES

The Local and State Coordinating Committees were responsible to promote the Upper Conestoga RCWP in the local community. This was done originally through a newsletter that was sent to approximately 300 farmers. This newsletter was sent out annually until 1986, when the extension office began sending newsletters. In the early years of the project, 50 posters and 1,500 pamphlets were printed and distributed to make the community aware of the Upper Conestoga Headwaters RCWP project. All agencies participated in RCWP promotion as a part of their usual mission to agriculture.

Information and education activities generally involved two or more agencies. All activities were sponsored by the Local RCWP Coordinating Committee.

4.7 INTER-AGENCY ACTIVITIES

The Local Coordinating Committee met frequently to coordinate RCWP activities. Information and education functions were planned with the committee. Most informational meetings and tours were multi-agency activities involving RCWP program functions and comprehensive monitoring.

Information and education methods used are as follows:

- Release news to newspapers, radio and television stations.
- Distribute information on the RCWP through newsletters of cooperating agencies.
- Present public meetings and school programs.
- Give tours showing improvements in the Conestoga Headwaters Program area and of monitoring sites to local farmers, cooperating agency personnel, and the public.
- Visit farmers to insure that they get information on RCWP water quality planning.
- Demonstrate in farmers fields improved nutrient management and BMP technology.
- Distribute RCWP pamphlets and posters. On the RCWP project application the primary responsibility for I and E was assigned to a subcommittee to be named by the Conestoga Headwaters Program Coordinating Committee and chaired by Cooperative Extension Service (CES).
- Provide on the farm technical assistance in nutrient planning for crops in an effort to reduce annual nitrogen and phosphorus application rates on farmland.

4.8 PUBLIC INVOLVEMENT

The Lancaster County Conservation District provided a no-til planter to farmers in the Conestoga Headwaters RCWP in 1984. A no-til demonstration was held in the spring in conjunction with the Eastern Lancaster School District. Twenty-six farmers in the RCWP area used the planter on 324 acres. Fifteen farmers said that it was their first experience using a no-til planter. Many of those farmers were still utilizing no-til planting in 1991. This program provided positive contacts with farmers, many of whom later added other water quality Best Management Practice. RCWP cost-sharing enabled two farmers to receive the Lancaster County Conservation District's Special Cooperator Award. Another RCWP contracted farm received the annual Outstanding Cooperator Award.

The Eastern Lancaster County School District, in 1980, employed two full-time vocational agriculture instructors to work with local farmers. In 1988, one adult farmer instructor position was eliminated. Having a credible educational program like this in place at the conception of the project was a key element to the success of the project. Farmers had confidence in educational programs. The adult farmer program provided a water quality educational program. Approximately half of the Upper Conestoga Headwaters was part of the Eastern Lancaster County School District. Programs developed by the adult farmer instructors were also attended by farmers outside Upper Conestoga Headwaters area.

Approximately 9 meetings and tours, each attended by an average of 90 farmers, were held each year by the adult farmer instructors. One-third of these meetings dealt with pesticide use and safety. The rest of the meetings addressed the use of Best Management Practice and other water quality related issues. Each instructor made approximately 150 individual farm visits each year to discuss Best Management Practices and water quality. Five newsletters were sent out annually to over 700 farmers. Parts of these newsletters focused on water quality practices. Nutrient management test plots were conducted on local farms each year in cooperation with the Penn State Agronomy Department.

Ephrata Area High School also employed a vocational agriculture instructor with part-time responsibilities in adult farmer education. This instructor provided educational meetings in an area of northern Lancaster County that included approximately one-third of the Upper Conestoga Headwaters. Some of the biweekly meetings which were held each winter addressed Best Management Practice and water quality. A field day was held in 1990 which specifically addressed nutrient management. Part of the field day included visits to RCWP test plots and monitoring sites.

4.9 LIST OF PUBLISHED GENERAL INFORMATION MATERIAL

Conestoga Headwaters RCWP Annual Reports 1982-89, Berks and Lancaster Counties, Pennsylvania.

Summary of 1984-90 Research in Lancaster County, R. H. Fox and J. D. Toth.

Application of an On-Farm Monitoring and Measurement System in the Management of Farm Nutrients; Les. E. Lanyon, Associate Professor of Soil Fertility, Department of Agronomy, The Pennsylvania State University, University Park, PA 16802.

Biochemistry of Nitrogen from Dairy Cattle Manure and the Cycling Effects of Carbon and Nitrogen on Nitrate Leaching from Soils; Dale E. Baker, Leon E. Marshall, Mary K. Amistadi, Karen Simmons, Carol S. Baker, James Phillips, Erik Lotse, and Joseph Senft.

Economic Evaluation of the Conestoga Headwaters Pennsylvania RCWP Project; C. Edwin Young and Bradley M. Crowder, U. S. Department of Agriculture, Economic Research Service.

Water-quality reports and their publication outlet or status are listed in Appendix F.

5.1 FINDINGS AND RECOMMENDATIONS

FINDINGS: The National RCWP institutional procedure provided adequate guidelines for USDA agencies, Environmental Protection Agency, and state agencies to organize a functional unit for RCWP implementation. Agency missions and expertise when properly coordinated met the program needs.

- The RCWP Committee system (national, state, local) provided adequate project guidance, technical expertise, funding, and control to implement a successful project.
- Flexibility of authority to plan, develop and implement the project at the local RCWP level permitted use of initiative by personnel familiar with the land resources, community social and economic structure, and other factors applicable to a site specific project.

RECOMMENDATION: Successful projects need to identify water quality problems and the causes of the problems. It may be necessary to eliminate or reduce the cause if the problems are to be solved. Project management may need to address the cause of problems as well as the current problem.

RECOMMENDATION: Institutions with agricultural expertise need to coordinate activities with water quality agencies in an effort to meet the environmental goals and the economic and social goals of agriculture.

RECOMMENDATION: Institutional impacts of agri-business, banking, feeds, equipment, processors, and marketers need to be assessed when determining the cause of agriculture related water quality problems. Solving the problem may be impossible without making institutional changes that will have a positive environmental effect on land use activity. Integration of agriculture production with processing and marketing generally results in intense cropping and high density of animal units which may degrade water quality.

RECOMMENDATION: Projects of this type need to have an in-depth assessment of water quality prior to implementation of field BMP's. The assessment should accurately determine the water quality problems, what caused the problem, whether the cause or causes are decreasing or are increasing. Project administration needs to recognize and develop strategies to satisfactorily resolve the problems. Administration needs to be flexible enough to permit changes in BMPs, project technical approaches, social and economic change in the community, and other factors that may be having a positive or a negative impact on the water quality improvement effort. Use other complementary programs, if any, to assist in the project administration and the improvement of water quality.

5.2 INSTITUTIONAL ARRANGEMENTS

The Pennsylvania State RCWP Coordinating Committee was responsible to administer RCWP in accordance with national RCWP policy. Within this policy the State Coordinating Committee authorized the Lancaster County RCWP Local Coordinating Committee to plan and implement the Conestoga Headwater Project. Local Coordinating Committee plans were subject to approval by the State Coordinating Committee.

The State Coordinating Committee chaired by the State Executive Director of Agricultural Stabilization and Conservation Service provided a coordinator to work with the Local Coordinating Committee. Considerable flexibility by the local committee was permitted. The State Coordinating Committee supported the Local Coordinating Committee in most of their ideas and approaches to solving agricultural related water quality problems. The National RCWP Coordinating Committee was very supportive of the State and Local Coordinating Committees.

National RCWP original strategy assumed BMPs would be implemented on RCWP contracted farms only.

By recommendation of the Local and State Coordinating Committees, the National Coordinating Committee permitted the Conestoga Headwaters Project to implement the following changes in water quality strategy:

- Some cost-share funds were transferred to technical assistance through the Cooperative Extension Service to provide a nutrient management service to all farms in the watershed without regard to approved RCWP contracts.

- Additional technical service funding was provided to the Soil Conservation Service for servicing BMPs on non-RCWP farms in the project area.

- Ample funding was made available to implement comprehensive monitoring in accordance with State and Local Coordinating Committee's plans. These plans were expanded or changed several times as monitoring needs were determined.

- Funding was provided to finance two experimental studies. One concerned nutrient residues remaining after a crop was harvested and its transport through the soil to groundwater. This involved deep soil testing to characterize nitrate vertical movement. The other considered quantity and quality of farm nutrients (applied to fields) produced via manure and crop residues. These factors were used to assist in developing farm nutrient budgets for farmers. Results improved nutrient management planning.

- Funding was authorized to permit payment for exporting excess manure from field site #2 of the comprehensive monitoring function. This facilitated balancing nutrient inputs on the site to the crop needs and contributed to reduction of groundwater pollution.

5.2.1 Conestoga Headwaters Project Administration

Administration and project coordination - Agricultural Stabilization and Conservation Service, USDA - Project contracting, cost-sharing and provided RCWP committee chairpersons.

Technical services - Soil Conservation Service, USDA - Water quality planning and technical supervision of RCWP contracts.

Information and education - Cooperative Extension Service - Provided most information and education for farmers and the public. Nutrient management technical service - Pennsylvania State University in cooperation with Department of Agronomy.

Economic assessments - USDA Economic Research Service provided the economic assessments for this project.

Experimental nutrient management functions - Pennsylvania State University Agronomy Department.

Comprehensive monitoring management - Pennsylvania Department of Environmental Resources, Bureau of Water Quality under contract with Agricultural Stabilization and Conservation Service, USDA.

Comprehensive monitoring technical activity - U.S. Geological Survey by contract with Pennsylvania Department of Environmental Resources and in cooperation with Pennsylvania Department of Environmental Resources and the Conestoga Headwaters RCWP Committees provided most of the field and technical monitoring. United States Geological Survey also provided approximately fifty percent of the funding for monitoring surface and groundwater.

Others - Pennsylvania Department of Agriculture, Lancaster Conservation District, Pennsylvania Department of Environmental Resources Bureau of Soil and Water Conservation and others assisted in project functions.

Coordinating Committees:

The Local Coordinating Committee met quarterly or more frequently if called by the Chairman, Agricultural Stabilization and Conservation Service County Executive Director.

The State Coordinating Committee met semi-annually or on an as needed basis. During the planning and development of the project, meetings at the State and Local level were more frequent.

A State Coordinating Committee representative usually met with the Local Coordinating Committee to facilitate communication between the committees. A Local Committee representative also met with the State Coordinating Committee.

Administration of the Conestoga Headwaters Project worked well. Open communication between agencies and levels of administration are very important to a successful project. Coordinator positions are a must.

5.2.2 LCC/SCC Coordination

Coordination and cooperation between the Local Coordinating Committee and the State Coordinating Committee was excellent throughout the RCWP. The State Coordinating Committee reviewed proposals, adjusted RCWP allocations and provided liaison with the National Coordinating Committee and the Comprehensive Monitoring and Evaluation team. The Local Coordinating Committee led in the implementation and fine-tuning of Water Quality Plans to fit the specific needs of RCWP farmers.

Planning flexibility permitted by the State Coordinating Committee allowed for important corrections early in the program to help make a successful project. Agency guidance and prompt responses by the State Coordinating Committee were invaluable to local project personnel.

5.2.3 BMP Maintenance Tracking

Best Management Practice (BMP) maintenance reviews completed by Soil Conservation Service and Agricultural Stabilization and Conservation Service personnel indicate 98% compliance. Six (6) active contracts are completing BMPs without RCWP cost-sharing in 1992.

5.2.4 Assessment of Assistance Provided by Federal Agencies

Environmental Protection Agency (EPA) - Region III EPA provided a representative who met with the State RCWP Coordinating Committee. EPA guidance and assistance in planning and implementation of the project assured compliance with federal water quality policy.

Soil Conservation Service (SCS) - RCWP water quality planning, technical supervision, and performance assessments were properly completed by the SCS. State and County personnel were committed to solving the water quality problems. They enthusiastically encouraged farmers not in RCWP to implement BMPs.

Agricultural Stabilization and Conservation Service (ASCS) - Administration at the national, state, and local levels was adequate. Administrative and financial needs of the project were met.

It appeared, at times, that national level technical guidance to states was lacking. However, this may be desirable management because it allowed maximum use of state and local initiative to solve local problems. It permitted maximum learning processes by personnel in a local experimental project setting. Lessons learned are accumulated in the national reporting process.

Cooperative Extension Service (CES) - CES provided considerable agricultural data and guidance in the project development.

Media information was managed by CES. Water quality information was a part of Extension meetings involving dairy, poultry, livestock, and crops. The educational efforts of CES have created county wide awareness of Lancaster County agricultural water quality problems.

State level CES personnel provided excellent support in the identification of nutrient management problems, the development of a nutrient management planning process, and the supervision of a nutrient management staff to assist farmers in agricultural nutrient management.

Economic Research Service (ERS) - ERS participated in the RCWP planning and development process. In the period 1982 through 1986, ERS conducted several economic studies of benefit to RCWP. In 1984, ERS used the CREAMS model to evaluate the effectiveness of RCWP BMPs. This model measured soil loss reduction at the field edge and evaluated nitrogen and phosphorus reductions because of reducing the soil loss. ERS completed their final report in 1986. They projected RCWP activity and results through 1991.

Lancaster County Conservation District (LCCD) - In cooperation with Pennsylvania Bureau of Soil and Water, the LCCD completed an in-depth farm management survey in the Conestoga Headwaters Project. Data analysis indicated the very high application of manure, fertilizer, and other nutrients to farms. The survey results showed a need for nutrient management planning in the Project area.

The Conservation District also provided educational assistance in contracting, no-til farming, manure equipment calibration, and other functions that complement RCWP.

Eastern Lancaster County School District - Adult Farmer Program (AFP) - Instructors and adult farmers provided education on water quality, encouraged RCWP contracting, conducted nutrient experiments in the field, and assisted in implementation of some BMPs.

Pennsylvania Department of Environmental Resources, Bureau of Water Quality (PaDER) and United States Geological Survey (USGS). -

RCWP comprehensive monitoring and evaluation was provided by the PA DER by contract with Agricultural Stabilization and Conservation Service, USDA. USGS contracted technical monitoring with the PA DER.

Monitoring management responsibility stayed with PA DER. USGS funded approximately fifty percent of the monitoring cost. Agricultural Stabilization and Conservation Service, Soil Conservation Service, and Cooperative Extension Service representatives participated in a monitoring planning committee.

These agencies provided the monitoring, planning, field implementation, water quality analysis, evaluation and monitoring reports.

The monitoring team and the RCWP USDA agencies cooperated very well in developing and implementing comprehensive monitoring. BMP implementation and water quality plans for farm monitored sites were coordinated with monitoring strategies.

Monitoring reports are in sections 6 and 7 of this report.

Other Assistance - The Lancaster County Commissioners, Eastern Lancaster School District, Ephrata School District, township officials and others supported the Conestoga Headwaters RCWP project. The local news media was cooperative in reporting RCWP activities.

5.3 ECONOMIC EVALUATION

The total amount of money spent on farmer financed BMPs was greater than for the total spent on cost-shared BMPs.

Three BMPs, BMP2, animal waste management systems, BMP4, terrace systems and BMP7, waterway system, accounted for more than 65% of all cost-shared expenditures. These are all relatively expensive BMPs.

Fertilizer management (BMP15) through nutrient management plans written by the CES Nutrient Management Office was used on 24,000 acres on more than 300 farms. BMP15 appears to be very cost effective in this project.

5.3.1 Installation Costs of Each BMP and the Proportion Cost-Shared by RCWP

Average costs for individual BMPs are listed in Table 5-1.

Costs for BMPs increased during the course of the RCWP by close to 100%. Most of the increase was due to excavation cost.

Table 5-1.--BMP installation costs and proportion paid by RCWP

[Costs are average costs for the duration of the project; N.A., Not Available]

Best Management Practice	Unit	Average installation cost/unit	Percent cost-share
BMP 1 Permanent Vegetative Cover	Acre	$50.00	50
BMP 2 Animal Waste Management	No.	15,000.00	50
BMP 3 Stripcropping System	Acre	10.67	50
BMP 4 Terrace System	Mile	14,731.20	75
BMP 5 Diversion System	Mile	16,420.80	75
BMP 6 Grazing Land Protection System	No.	618.00	50
BMP 7 Waterway System	Mile	18,585.60	75
BMP 8 Cropland Protective System	Acre	12.06	50
BMP 9 Conservation Tillage Systems	Acre	N.A.	0 *
BMP 10 Stream Protection System	No.	500.00	50
BMP 11 Permanent Vegetative Cover on Critical Areas	Acre	N.A.	50
BMP 12 Sediment Retention, Erosion Water Control Structures	No.	3,712.00	50
BMP 15 Fertilizer Management	Acre	N.A.	0
BMP 16 Pesticide Management	Acre	N.A.	0

* LCCD rented no-till planters to farmers for a nominal fee during the first 3 years of the project. Costs for BMPs increased during the course of the RCWP by close to 100%. Most of the increase was due to excavation cost.

5.3.2 Total Cost-Share Assistance

Table 3-2 shows cost-share by practice accomplishments through 1991. RCWP contract outlays for 1982-1991 totalled 0.8 million dollars. Additional estimated outlays of 0.7 million dollars on contracted BMPs was spent by farmers. Noncost-shared BMPs in the same period valued at $1.54 million were implemented by other farmers.

5.3.3 Total RCWP Project Expenditures

Table 5-2 shows total expenditures by the various agencies cooperating in the Conestoga Headwaters project.

5.3.4 Insights or Observations

BMP15, Fertilizer Management, may have an immediate effect on Non-point agricultural pollution. In this project area, most nutrient management plans resulted in an immediate reduction of commercial fertilizer which resulted in a potential reduction of nutrient pollutants. This may not occur in agricultural areas where excess nutrients are not being applied.

BMP 15 is very cost effective in this project area due to a substantial reduction of nitrogen and phosphorus being applied to land. The same results may not be expected in areas where reductions may be minimal.

Reduction in commercial fertilizer application of nitrogen, phosphate and potash by farmers resulted in lower costs for many farmers. These reductions in fertilizer use were verified through a survey conducted by the Nutrient Management Office. The reduction reflected recommendations by nutrient management office personnel.

Table 5-2.--Conestoga Headwaters Cost by Function and Agency (1982 - 1991)

Function/Agency		Cost
RCWP Costs have Contracts		
ASCS - USDA		$ 793,952
	Subtotal	793,952
Comprehensive Monitoring		
ASCS - USDA contract with the PA Department of Environmental Resources		1,086,930
ASCS - USDA Soil and Manure Testing		16,356
PA Department of Environmental Resourses		48,000
US Geological Survey (50-50 contract with the PA Department of Environmental Resources)		1,135,865
SCS-USDA)		20,400
	Subtotal	2,307,551
Technical Services		
USDA - Soil Conservation Service		784,013
USDA - Cooperative Extension Service		25,000
Nutrient management Planning - Cooperative Extension Service, PA State University		459,404
	Subtotal	1,268,417
Information and Education		
Cooperative Extension Service		10,000
Experimental Studies and Projects (3) PA State University		78,468
	Subtotal	88,468
Economic Assessment - Economic Research Service - USDA		175,000
	Subtotal	175,000
Administration		131,590
	Subtotal	131,590
ASCS - USDA		1,587,778
TOTAL COST		$ 4,764,978

BMP2, Animal Waste Management, may or may not be effective in reducing pollution on site specific farms. In cold climates daily spreading or interval spreading of manure on frozen or excessively wet land may result in high levels of surface runoff pollution. On farms producing nutrients in manure in excess of the farm crop needs storage of manure may increase the excess nutrients available to surface and groundwater pollution. Most storage systems for manure reduce nutrient aerobic loss compared to daily spreading. Animal Waste Management may have a very positive water quality and economic effect on farms where nutrients saved through adequate storage and proper application will be utilized by crops produced.

Animal Waste Management and BMP 15, Fertilizer Management, need to be paired for effective Animal Waste Management and nutrient management. The individual farm needs for these practices should result in a system designed to meet the farm nutrient needs and maximize water quality.

BMP4, Terrace System, seemed to be the most effective BMP in the RCWP for controlling cropland soil erosion and keeping the resulting sediment and attached pollutants from reaching the stream. It has been estimated that every ton of sediment reaching the stream carried with it six (6) pounds of nitrogen and 3.3 pounds of phosphorus. Other BMPs can control erosion but they usually require a change in crops and most landowners were unwilling to make that change. Terraces have a long life span and will continue to control soil erosion for many years to come.

BMP10, Stream Protection System, probably would have had an immediate positive impact on water quality had more farmers used it.

This BMP is beginning to be appreciated in the county. The Pennsylvania Game Commission has a very active stream fencing program.

Farm water quality plans should incorporate the BMPs to meet individual farm needs. Some BMPs appear to be more cost-effective than others. However, a combination of BMPs such as nutrient management and erosion control may be needed.

5.3.5 and 5.3.6 Impacts of the BMPs on Producers' Costs and Returns and Off-Site Benefits of RCWP

The Local and State Coordinating Committees have determined that the economic evaluation completed by the Economic Research Service, USDA, in 1986, satisfactorily addresses the economic conditions in this project. The 1986 report is reprinted in its entirety.

ECONOMIC EVALUATION[1]
1986

Introduction

This chapter summarizes the economic evaluation of the Conestoga Headwaters, Pennsylvania Rural Clean Water Program (RCWP) project. The economic analysis assumes that the primary focus of RCWP is implementation of cost-effective BMPs to achieve water quality benefits. Water quality benefits occur when the level of water use increases or the costs of existing use decrease due to reductions in the delivery of nonpoint source pollutants such as sediment, nitrogen, phosphorus, and pesticides. Greater details on the economic evaluation can be found in annual progress reports and in separate technical reports as listed at the end of this chapter.

The impacts of RCWP, since they are still in the process of occurring, have been estimated by comparing the projected situation with the BMPs fully implemented with the preproject situation and a projected without BMPs situation. Although farmers have the option of discontinuing the RCWP practices, this analysis assumes they will not. Thus, the analysis can be considered as a "best case" scenario. The objectives of the economic evaluation are to 1) estimate the costs and effectiveness of BMPs in reducing delivery of nonpoint source pollutants; 2) estimate the economic impacts of RCWP on agriculture; 3) estimate the economic value of water quality improvements and 4) assess the social benefits and costs of the project, ie. compare the total benefits and costs of water quality improvements.

In order to evaluate the economic impacts of RCWP it was necessary to relate implementation of BMPs to changes in water quality and subsequent changes in the economic value of water uses. This was accomplished by relating physical and cost data from RCWP participation to expected changes in water quality through the use of monitoring data, past research results, and simulation models. The simulation models used ranged from the relatively simple Universal Soil Loss Equation (USLE) to complex computer simulation models such as the Chemicals, Runoff, and Erosion From Agricultural Management Systems (CREAMS) model.

Description of Project Area

The Conestoga headwaters RCWP project is located mostly in the northeastern portion of Lancaster County, Pennsylvania. There are 110,000 acres of land 1,250 farms in the project's watershed. Most of the farmers in the project area follow Amish and Mennonite farming traditions. The topography is undulating to rolling with 0-40 percent slopes, with an estimated 35,000 people living in the watershed. However, water supplies for 175,000 residents and 2,000 commercial industries originate in the watershed.

The average farm size in the project area is 52 acres, with most of the land used for feed and forage production for approximately 1,000 intensive dairy and livestock operations. Many of these operations are diversified to include poultry and hog production. There is an average of 2 animal units (AU) per acre of farmland.[2] About 25 tons of manure are produced for every acre of cropland, and the average manure application on corn land is 40 tons per acre, which substantially exceeds crop nutrient requirements.

The agricultural trends for the past 25 years in southeastern Pennsylvania have caused recent concerns about agriculture's role in water quality degradation. Lancaster County and surrounding areas have experienced rapid increases in crop and animal production. This production intensity is partially explained by: 1) urban development pressures on agricultural and, especially near the city of Lancaster; 2) proximity to several large East Coast markets; and 3) Amish and Mennonite family farming traditions, which resulted in the division of farmland among children into progressively smaller pieces of farmland over time. This factor was significant in determining large number of small, intensive farms in Lancaster County.

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[1] The economic evaluation is the responsibility of the Economic Research Service (ERS), U.S. Department of Agriculture. Principal ERS economists involved have been C. Edwin Young and Bradley M. Crowder.

[2] An animal unit (AU) is equivalent to 1,000 pounds of animal liveweight.

Because of the diminishing supply of available land, animal operations have been expanded to increase incomes and better use family labor. In table V-1, this trend toward more intensive livestock production is illustrated for the primary livestock enterprises in the county. The project area comprises 17 percent of the county's agricultural land and 23 percent of its livestock production.

BMP Implementation and Effectiveness

Participation in RCWP

Participation in the RCWP project has been low. Of the approximately 1,250 farms (400 of which are in the critical area), 75 farmers participated in the project. Approximately 5,015 acres of land have been contracted under RCWP. About 4,000 acres are cropland with the remainder mostly pasture and woodland.

The relatively low rate of participation in the project has been attributed to the reluctance of the Amish and Mennonite population to participate in a government cost share program. Another possible explanation is the low economic return that results from BMP implementation when a farmer has excess nutrients. If nutrients are saved due to implementation of BMPs, a farmer would have an incentive to participate if participation reduces his operating costs. Also, there has been an emphasis on the use of structural soil conservation BMPs and on reducing soil loss to tolerable (T) levels on the entire farm. This emphasis may have discouraged some farm operators from participating in the project.

The median number of acres included per contract for the 75 farms was 60 at the end of FY 1986, with over 70 farms contracting less than 100 acres. Only 10 contracts were for less than 30 acres. Two-thirds of the farms had contracts that ranged between 30-70 acres.

BMP Implementation Under RCWP

Table V-2 shows the approximate final implementation of practices as contracted through completion of the project in 1991. The BMPs are shown either as area treated or as the number of farms receiving the

Table V-1. Numbers of animals, crop acreage, and commercial fertilizer purchases, Lancaster County, PA, 1970-1983

Item	1970	1975	1983
Cows milked (number)	67,000	81,200	112,300
Cattle and calves (number)	194,000	246,000	272,500
Hogs	109,000	169,100	315,000
Livestock value (thousand $) (cattle, calves, sheep)	59,811	94,327	200,370
Broilers (thousands)	18,028	24,822	43,950
Layers (thousands)	3,109	3,592	7,628
Corn grain (acres)	105,300	115,500	117,700
Corn silage (acres)	37,300	61,220	78,300
Field & forage crops total (acres)	322,626	327,700	328,000
Nitrogen purchased (tons)	NA[1]	8,291	10,118
Phosphate purchased (tons)	NA[1]	7,970	6,581
Potash purchased (tons)	NA[1]	1,198	6,239

[1] NA = Not available.

Source: Pennsylvania Crop Reporting Service. *Crop and Livestock Annual Summary* Commonwealth of Pennsylvania, Department of Agriculture, Harrisburg, PA. 1970, 1980, 1983.

treatment. The numbers represent BMP adoption due to RCWP except where noted. However, it is recognized that some BMP adoption has occurred in the project without RCWP cost sharing, mostly with SCS technical assistance and ASCS cost sharing. Some BMPs have been implemented with assistance from personnel with the Eastern Lancaster County School District. Conservation plans have been developed on over 3,000 acres on farms not participating in RCWP. This type of BMP implementation is expected to increase in the future. A portion of the non-RCWP BMP adoption, whether cost shared or financed privately, is due to the education of farmers in the RCWP project area about the pollution problems and how to solve them. This BMP adoption is included in the economic analysis.

All but one of the farmers participating in RCWP contracted for fertilizer and pesticide management. This is important because of the importance of manure and fertilizer management and pesticide management to reduce pollutant loading of streams and groundwater.

Almost all of the participating farmers who have animal operations with 1.5 or more AU per acre also contracted for the animal waste management BMP.

Similarly, all farmers contracted for conservation cropping, which required farmers to minimize their tillage operations and the time between operations, and to relative to structural practices, for example, and these practices represent sound management alternatives to the profit maximizing farmer who wants to reduce erosion losses.

Crop residue management has been instituted on 3,900 acres of cropland in the project (table V-2). Some farmers were managing residue reasonably well before RCWP and some were planting cover crops. Partly as a result of RCWP, it is estimated that more than half of the watershed's farmers plant winter cover crops where residue is harvested. Only 2 of the 75 farms contracted have not included this BMP.

Contour stripcropping has been contracted on a high percentage of the cropland to be treated. Almost 40 percent of the contracted cropland included stripcropping while about 90 percent of the cropland will be contoured (including land which is terraced).

Table V-2.--BMP implementation in the Conestoga headwaters RCWP watershed, 1981-91.

BMP No.	BMPs	BMP Implementation RCWP	Non-RCWP
1	Permanent vegetative cover (acres)	138	100
2	Manure storages (number)	38	30
3	Stripcropping (acre)	1,526	1,200
3	Contour cropping (acre)	1,353	--
4	Terrace systems (miles)	88	15
5	Diversion systems (number)	37	5
7	Sod waterway systems (number)	60	10
8	Crop residue mgmt. and winter cover (acre)	3,904	10,000
9	Reduced tillage (acre)	1,500	10,000
9	No-till (acre)	900[2]	[3]
10	Stream protection fences (number)	13	25
11-12	Other structural practices (number)	20	--
15-16	Fertilizer and pesticide management (acres)	3,904	10,000

[1] Projected levels of BMP installation provided by ASCS.
[2] Land under no-till is duplicated in some contracts by land under reduced tillage, or is tilled for crops other than corn.
[3] No-till acreage was included with reduced tillage.

Thirteen farms will have fences established to prevent livestock from getting in the streams, thereby reducing nutrient loads, fecal coliform loads, and streambank erosion. Where appropriate, fences could be expected to have a considerable effect on water quality. In addition, 138 acres of permanent vegetative cover were contracted.

Manure storage structures were contracted on about half the farms using RCWP cost sharing. About two-thirds were for dairies and one-third for swine operations, with 1 beef operation. The number of manure storages is proportionate given the distribution of dairies and swine operations in the watershed. A large number of beef feedlots exist in the watershed, but storages are uncommon probably because of the small number of animals found on most feedlots, the type of housing, and the number of days per year that beef cattle are pastured.

Reduced tillage using a chisel plow or disk has been contracted on approximately 1,500 acres of cropland as a result of RCWP, or more than one-third of the contracted cropland. No-till acreage is footnoted in table V-3 because much, perhaps half, of the acreage that is planted in corn using no-till also is under reduced or conventional tillage for some corn and other crops. Many contracts are written as "some no-till" to be used for corn planting. Approximately half of the cropland acreage contracted under RCWP has included reduced tillage or no-till.

About half the participating farms have one or more diversions to be installed. Terrace systems, most of them with pipe outlets, also have been contracted on about half of the treated cropland. Sod waterways have been contracted on nearly all participating farms, some with more than one waterway. About half of the acreage that is scheduled to receive structural practices is tilled using conventional practices, while following guidelines under the conservation cropping BMP. Contracts signed since the end of 1984 have required conservation tillage on about 75 percent of the rowcrop land.

Other structural practices--siltation basins, spring development and water troughs, one filter strip, barnyard paving, gutters and spouts, and rock fill in one severely eroded gully--also have been contracted in specific instances which called for special structural measures.

BMP Implementation Outside of RCWP

BMP implementation outside of RCWP could outweigh that of RCWP through 1991 (table V-2). Factors involved are: (1) The farmers and the government agencies in Lancaster County and throughout Pennnsylvania have become aware of the water quality problems in the project area and elsewhere in southeastern Pennsylvania. Educational services and technical assistance from the SCS, Cooperative Extension Service, and Vocational-Agriculture teachers will help make farmers aware of the consequence of their actions (or lack of actions) and assist them in implementing BMPs. (2) Cost sharing from ACP, the

Table V-3.--Effects of BMPs on soil and nutrient losses for corn silage following corn silage, with a 5-percent slope, 30 tons per acre of manure, and daily spread.

BMP	Soil loss (tons/acre)	Nitrogen loss: Percolate	Nitrogen loss: Surface	Nitrogen loss: Total	Phosphorus loss (pounds/acres)
			(pounds/acres)		
No BMPs	11	50	68	118	31
Terraces	3	52	29	82	12
Reduced-till	6	50	45	95	20
No-till	3	45	33	78	14
All BMPs[1]	1	54	14	69	5

[1] All BMPs include terraces, contouring, stripcropping, residue management, and sod waterways.

Chesapeake Bay State Cost- Sharing Program, and other programs in the future will continue to provide financial support for BMPs. (3) Current nutrient management research, pilot programs for manure marketing and methane digestion, better soil nitrogen tests, and other future developments will make nutrient and soil conservation more attractive to farmers. (4) The threat of State and Federal regulation of agricultural nonpoint source pollution will continue to provide incentives to adopt BMPs voluntarily. (5) Future programs may be less restrictive in their contract requirements for participation. Voluntary cooperation in the future is partially dependent on allowing farmers the freedom to adopt those practices which are cost effective, inexpensive, and compatible with their goals and abilities.

In the future, cropland protection (residue management, winter cover crops) and conservation tillage should be adopted on a considerably greater percentage of the land in the watershed due to their reduced or similar costs and greater effectiveness, compared to conventional practices. Likewise, fertilizer and pesticide management, which also are beneficial to farmers by reducing costs, are expected to gain increasing acceptance from farmers in the future. Manure storages, terraces, and sod waterways are the other highly significant BMPs that are estimated to have a large effect on the watershed. The use of these practices by farmers participating in RCWP will demonstrate their value to other farmers in area.

BMP Effectiveness

A critical link in an economic evaluation of a water quality program such as RCWP is the link between BMPs and offsite users of the water resource. This link can be established through the use of water quality monitoring results. In the case of the Conestoga Headwaters RCWP project, monitoring data do not provide sufficient information to support the economic evaluation for two reasons. First, a long time period is required to establish monitoring sites and to provide statistically significant relationships between water quality parameters and BMPs. Second, an economic evaluation examines a wide variety of BMP implementation scenarios. The cost of monitoring a sufficient number of BMPs to support an economic evaluation would be prohibitive.

For this analysis a state-of-the-art, physical-based simulation model was selected as a means of obtaining consistent and realistic information on the relationships between BMPs and water quality. The CREAMS model was used for this analysis. Results from the use of the CREAMS model were compared to available monitoring data for the Conestoga Headwaters RCWP project as a means of verifying the modeling results. The modeling results are consistent with the available monitoring results regarding the relative effectiveness of the systems of BMPs.

The results from the CREAMS modeling have been reported elsewhere.[3] Table V-3 is included in this report to illustrate the modeling results. BMPs are effective at reducing soil and nutrient runoff losses. BMPs do not appear to be effective at reducing percolate losses of nitrogen. This latter result is important for the Conestoga Headwaters RCWP project, since protection of groundwater resources is a goal of the project.

Economic Impacts on Participating Farmers

BMP Costs

All farmers except one who have signed RCWP contracts have applied three BMPs, and two others where appropriate, almost all without cost-sharing. These three include fertilizer management, pesticide management, and crop residue management which have generally been required on cropland. Where necessary, animal waste management and pasture and hayland management have been required. While yields may improve as a result of better farm management and offset the costs, these practices nonetheless impose real time and labor costs on farmers, and may alter their usual ways of doing things.

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[3] Crowder, Bradley M. and C. Edwin Young. Modeling Agricultural Nonpoint Source Pollution for Economic Evaluation of the Conestoga Headwaters RCWP Project. Staff Report No. AGES850614, Economic Research Service, USDA, Washington, D.C., 1985, 70 pp.

Similarly a number of other practices that have been contracted extensively have generally not been cost shared. Among these are stripcropping (which recently has been cost shared), contouring, and reduced tillage and no-till practices. No-till on some farms was cost shared under the Agriculture Conservation Program, rather than RCWP. The Conservation District supplied planters on some farms.

Cost sharing for structural practices only includes the installation costs. Cost sharing is not provided for maintenance of these practices, nor is the farmer compensated for the acreage taken out of rowcrop production as a result of installation, although hay can be harvested. Permanent vegetative cover eliminates rowcrop production on fields where it is established, and has been implemented only for critical erosion problems that cannot be solved by other field-level BMPs.

Farmers could be expected to continue practices that are not cost shared well beyond the expiration of RCWP contracts, by virtue of their implementing the practices at their own expense. Relatively expensive structural practices could be expected to be maintained for the life of the practice after RCWP, but some may be discontinued if cost-sharing is not provided for repair and maintenance of deteriorating terrace and diversion systems. A possibility exists that some land, cost shared to be planted in permanent vegetation, may be plowed for row crops if economic conditions are favorable to do so after the contracts expire.

Another adjustment, contrary to the objectives of the program, that farmers may make to improve profits after RCWP implementation is to increase the number of animals. The RCWP project has provided assistance for manure storage structures and improved animal manure management which should reduce labor requirements for animal- waste handling. As a result, some farmers may find it attractive to further expand the size of their animal operations, thus increasing the nutrient loading on crop and pastureland.

The total private costs for an average RCWP contract is about $5,600, or an average annual cost of $830 for 10 years.[4] These costs include farmers' shares of BMPs that are cost shared. They do not include indirect costs such as human capital investment, cropland taken out of production by structural practices, and inconveniences resulting to farmers. Thus the total direct private costs are $420,000.

Productivity Benefits

Many conservation practices protect water quality by reducing soil erosion and the associated chemical runoff. Therefore, long-run crop yields may be improved as a result of soil conservation. While there may be societal benefits from enhancement of long-run productivity, they are included here as primarily farmers' benefits. An objective measure of the crop productivity effects of BMPs was needed. These effects were estimated using USDA's Erosion Productivity Impact Calculator (EPIC) model. The EPIC Model is a mathematical simulation model that estimates water and wind erosion, and the impacts of erosion on crop productivity. The model is being used by USDA as part of the Resources Conservation Act (RCA) assessment. Representative EPIC results were obtained from the RCA analysis for the Conestoga Headwaters project area.[5]

Most of the land under contract with RCWP has slopes ranging from 4-12 percent. To calculate project-wide productivity benefits, we assumed that one-half of the contracted land had a 5-percent slope and one-half had a 9- percent slope. About 4,000 acres of rotation cropland, continuous corn, or hayland were under contract at the end of FY 1986. Using the proportions of hay (20 percent), corn grain (26 percent), and corn silage (28 percent) that approximate the project's crop mix, we derived an overall productivity benefit of $115,000 in the project area. Depending on the errors in our assumptions about average slopes and the crops grown, this figure could range between $65,000- $200,000. Because of the many soils in the project area and other difficulties, it was not possible to refine this estimate.

[4] All costs are expressed in 1986 dollars.

[5] Young, C. Edwin and Bradley M. Crowder. "Economic Evaluation: Conestoga Headwaters Rural Clean Water Program," 1985 Progress Report, Agricultural Stabilization and Conservation Service, USDA, Lancaster, PA, pp. 107-125.

Labor Savings from Manure Storage

Costs to farmers are reduced by RCWP due to reduced labor requirements for handling manure where storage systems were implemented. Labor savings from manure storage were estimated to range from $500 to $1,000 per year for most farms. Assuming a life of 30 years for the structures on the 38 farms with storage, the present value of these benefits is $306,000 with a range from $217,000 to $395,000 for the watershed.

Reduced Fertilizer Costs

The economic benefits of reducing fertilizer purchases are highly significant. The approved nutrient management program has targeted a total of 20,000 acres for inclusion, with the goal of reducing average per acre application of nitrogen and phosphates. Under this scenario, cost savings range from about $85,000 to $320,000 annually in the watershed. On a present value basis nutrient savings are estimated to be $1.6 million, with a possible range between $0.6 million to $3.5 million.

Net Economic Impact on Farmers

The economic benfits to farmers over the 50 year period 1981-2030 sum up to about $2 million (table V-4). When the net cost of implementing the BMPs (0.4 million) are subtracted from the benefits, participating farmers as a group maintain a net benefit before taxes of $1.6 million. After taxes the net benefit could be even larger, due to investment tax credit, depreciation, and current expense deductions from gross income. Also there may be some additional benefits such as reduced labor and equipment damage from prevention of gullies.

Water Quality Benefits of RCWP

Physical Impacts

Average soil erosion from cropland in the Conestoga Headwaters Watershed is 9.2 tons per acre per year, or a total of approximately 606,600 tons of soil per year for the 65,934 acres of land in crops. Agricultural land produces over 70 percent of the erosion in the watershed. Before RCWP, gross erosion from the contracted cropland would have been about 36,800 tons. After RCWP, assuming an average soil loss of only 3 tons per acre, only 12,000 tons of soil would be eroding from the 4,000 acres of treated cropland. This reduction of 24,800 tons of annual erosion represents about a 4 percent reduction in watershed erosion losses from cropland due only to RCWP contracting. Non-RCWP conservation practices also will control erosion in the project area. Over 3,000 acres have been planned without RCWP cost sharing, accounting for another 20,000 tons of reduced erosion.

Table V-4.--Economic impacts of RCWP on farmers, Conestoga Headwaters Project, 1981-2030.

Item	Single estimate (Million $[1])	Range (Million $[1])
Cost to farmers:		
Net BMP costs after government cost share	0.4	0.4
Benefits to Farmers:		
Productivity benefits	0.1	0.1 to 0.2
Labor Savings from manure storage	0.3	0.2 to 0.4
Reduced fertilizer costs	1.6	0.6 to 3.5
Total benefits	2.0	.9 to 4.1
Net benefits to farmers before taxes	1.6	-1.1 to 3.7

[1] Costs and benefits over 50 years discounted at 7.875-percent rate and converted to 1986 dollars.

Fertilizer and manure management plans, implemented as part of RCWP, have the potential to substantially reduce the amount of nitrogen and phosphorus delivered to streams, as well as fecal coliform bacteria. Conservation and structural practices can divert surface runoff losses of nitrogen to losses in deep percolate and ultimately groundwater, but can do little to reduce long-term delivery to streams. Nutrient management is needed that balances crop needs and nutrient availability with timely application and incorporation practices: farmers with excess manure nutrients could attempt to use them in a way that prevents delivery to water bodies and volatilize as much of the residue nutrients (above crop needs) as possible. Odor problems have been cited as a deterrent to this practice, however. Nutrients, especially nitrogen, find pathways to water bodies when applied in excess of plant needs. If a substantial portion of the over-fertilization typical in the RCWP project area can be eliminated, deliveries of nitrates in particular could be substantially reduced. SCS and participating farmers instituted nutrient management as part of farmers' resource management systems on virtually all of the land contracted under RCWP.

As a result of the low farmer participation in RCWP, improvements in water quality are small. Including both RCWP and non-RCWP treatment, about 12 percent of all the land in the watershed has been planned for treatment. This may or may not be significant for affecting water quality--no linkages have been made between nonpoint pollution and water quality to determine what level of treatment is necessary. Future conservation efforts, mostly through non-RCWP cost sharing and technical assistance, are expected to have significantly more impact than RCWP.

One positive spillover effect may be the educational benefits received by noncooperators. For those practices which enhance income, such as fertilizer and manure management and possibly conservation tillage, an increase in adoption could take place during and after RCWP among farmers in the watershed and elsewhere in surrounding counties. Such adoption could have significant water quality impacts.

Estimates of Benefits

While a comprehensive study of benefits was not performed for the Conestoga headwaters, it may be worthwhile to estimate the range of possible benefits attributable to the program. It must be emphasized that RCWP is an experimental program that is meant to identify which BMPs control the pollution problems in the projects. A major benefit of RCWP is its educational value in assessing the potential for BMPs to control a broad range of surface and groundwater pollution problems. The educational benefits of nutrient management practices in RCWP have enhanced the work of the Chesapeake Bay and other regional programs, and may be the project's greatest benefit toward water quality improvement.

Groundwater Benefits

A rough estimate of groundwater quality benefits was derived on the assumption that infants and pregnant women were the only ones affected by the nitrate and pesticide levels in local supplies. Because groundwater migrates in aquifers and eventually affects surface water quality, groundwater benefits are considered social and not just private effects. The long-term health risks of chemical exposure were not quantified, nor were the effects on livestock. We assumed that nitrate losses could be reduced by 30 percent of the previous level on treated land. Table V- 5 shows the estimates of RCWP benefits. Documented health effects from contaminated drinking water are difficult to find, and the low-end estimate of zero is shown for benefits. A great deal of uncertainty exists about elevated chemical levels in water, and there may actually be no damages. At the upper end of the range, we conservatively assumed damages were equal to the costs of providing bottled water to all the vulnerable population (pregnant women and infants) affected by drinking water that originates in the project, which could underestimate the actual damages. If cancer, acute toxic effects, or other damages could be documented, these benefits could be higher by several orders of magnitude.

Surface Water Benefits

The offsite benefits were derived from work done by Ribaudo for each of the nation's 10 Farm Production Regions.[6] Ribaudo estimated the benefits of reduced erosion in the Northeast over a 50-year planning horizon. Included among these benefits are reduced sedimentation of reservoirs, water treatment

costs, recreation damages, and flood damages. Ribaudo's benefits were adjusted to account for the relatively higher reduction of nutrients associated with runoff control in the project compared to the analysis, and the nutrient management program, if successful, should increase these benefits somewhat. Ribaudo's estimates were increased by 25 percent per acre of land treated in table V-5. Our estimates are very rough guesses about the benefits of RCWP and serve as boundaries that are correct perhaps within an order of magnitude.

Table V-5.--Estimates of total social benefits from the Conestoga Headwaters RCWP.

Benefits	Single estimate ($1,000)	Range ($1,000)
Surface water	150	65-200
Groundwater	51	0-85
Total	201	65-285

Economic Efficiency of the Project

The overall economic efficiency of the Conestoga Headwaters RCWP project is summarized in this section. A benefit/cost framework is used to evaluate the project, while alternatives for improving the economic efficiency of the project are discussed in a cost-effectiveness framework.

Project Costs

Estimated costs of the Conestoga headwaters RCWP project are presented in table V-6. Costs are divided into cost share expenditures and technical assistance and information and education costs. Total costs are $2.1 million. No costs are included for farmers since they are estimated to receive a net economic benefit.

Benefits Versus Costs

Benefit/cost ratios are traditional measures of economic efficiency for project evaluation. A benefit/cost ratio compares the present value of the stream of benefits to the present value of the stream of costs for a project. A project is judged to be economically efficient when the ratio exceeds one.

Comparison of the benefits and costs for the Conestoga headwaters RCWP project indicates that the costs of the project exceed the benefits (table V-6). The total social/water quality benefits, which is what the RCWP project was meant to deliver, sum to a point estimate of $201,000. The total government cost was $2.1 million, resulting in a public B/C ratio of less than 0.1. The overall "social" B/C ratio is total benefits divided by total costs, or 0.9, with a range from 0.4 to 2.0. The difference between the social and private B/C ratios signifies a substantial transfer payment from taxpayers to farmers in the watershed.

Strategies to Improve Project Performance

Alternatives to RCWP as implemented in the project are discussed in this final section. Attaining T levels, for soil and nutrients, is not the key to achieving water quality standards. Water quality standards are based on the water resource that is being protected. The key to protecting a water resource is reducing the total amount of sediment and nutrients delivered, thereby reducing pollutant loadings and enhancing

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[6] Ribaudo, Marc O. Reducing Soil Erosion: Offsite Benefits, Agricultural Economics Report Number 561, Economic Research Service, USDA, Washington, D.C., pp. 24

Table V-6.--Cost and benefits of RCWP, Conestoga Headwaters project, 1981-2030.[1]

Item	Single estimate	Range
	(Million $)	
Costs of RCWP:		
Cost share expenditures	1.0	
Technical assistance, information, and education	1.1	
Total government cost	2.1	
Benefits of RCWP:		
Water quality benefits	0.2	0.1 to 0.3
Net benefits to farmers	1.6	-1.1 to 3.7
Total benefits	1.8	-1.0 to 3.9
Total benefits minus costs	-0.3	-3.1 to 1.8
Water quality benefits minus costs	-1.9	-1.8 to -2.0

[1] Costs and benefits over 50 years discounted at 7.875-percent rate and converted to 1986 dollars.

downstream water user benefits. Thus control efforts should focus on reductions in delivery, which can be attained through either intensive or extensive treatment of a watershed.

With intensive treatment a set of fields can be treated to attain a given level of sediment reduction. If this strategy is followed and critical fields with high delivery ratios are selected, only a limited number of fields will need to be treated. Conversely, the identical level of pollutant delivery can be attained by treating a large number of fields while attaining a much lower erosion reduction per acre.

After pollution reduction by low-cost management practices is achieved, the marginal cost of further reduction becomes much greater. The land treated should maximize the savings of pollutants given the conservation expenditures (if improving water quality is the only goal), and this is not done by meeting T levels when financial resources are limited. The T planning was originally based on soil productivity for crop production. Extensive, not intensive (as done by farmers in RCWP), land treatment is necessary to improve water quality throughout the project area.

Terrace systems, installed to control erosion, may not be cost effective in achieving some of the goals of the project, specifically reducing and improving the aquatic environment within the watershed. Previously reported results for the economic evaluation show that conservation tillage practices reduce nutrient and soil losses at much less cost than terraces.

An example of the increasing average cost of soil and nutrient control is illustrated in table V-7. Low-cost practices such as reduced tillage and sod waterways provide nutrient loss control at similar cost. Notice that terraces deviate from the trend; i.e. its average cost per pound of pollutant reduction is substantially greater than other practices providing comparable control. The reader is reminded that there is an upper limit on the amount of control that an individual BMP can provide. If a high degree of control is necessary, higher-cost combinations of practices will be required. To efficiently control pollution from cropland, conservation tillage, sod waterways, contouring, winter cover, and other cost-effective practices should be implemented first so as to minimize the total cost per unit of pollution reduction.

The above discussion points out a dilemma between the divergence of private and public goals and the choice of public incentives to influence private decisions. Cost sharing has not been provided for some highly cost-effective practices such as conservation tillage, contouring, etc. On the other hand, cost sharing and the accompanying investment tax credits make terraces and other structures attractive to farmers for runoff control. With these incentives, the farmer can avoid purchasing new tillage equipment and continue farming as before with structures.

Table V-7. Cost-effectiveness of BMPs.[1]

Conventional practices	$/ton soil saved	$/lb N saved	$/lb P saved
Contour cropping	1.66	0.33	0.76
Conservation tillage	0.76	0.17	0.34
Sod waterways	0.99	0.24	0.45
Terrace systems	4.87	1.10	2.12
Diversion systems	2.06	0.41	0.78
Animal waste management	N/A	0.67	1.50
Conservation tillage and sod waterways	1.26	0.23	0.54
Contour cropping, conservation tillage, sod waterways, terraces	5.39	1.02	2.16
Conservation tillage, sod waterway, animal waste management	2.61	0.39	1.04

[1] Assumes continuous corn grain on a 5 percent slope.

An argument in favor of structures is that they will be on the land for 15 years or more, while conservation tillage and other management practices are performed on an annual basis. However, long-term cost sharing contracts could be used for these practices to insure continued use of low- cost management practices. Innovative use of cost sharing, even though it would essentially be subsidy payments for practices which are profitable, would reduce pollution and enhance the cost-effectiveness of RCWP.

Manure storage structures should be carefully evaluated on each farm as a cost- effective means of reducing nutrient and fecal coliform delivery to water supplies. Manure storage is recommended to improve the timing and application of nutrients. Losses of nitrogen to groundwater may be increased by incorporation of manure, either by tillage or injection, immediately after removal from storage.

Nutrient management has the potential to be the single most effective measure for initially controlling nutrient losses. Estimates of nutrient losses from the CREAMS modeling showed no practice was nearly as effective as reducing nutrient applications to levels compatible with crop needs.

Education of farmers is needed to assist them to better manage nutrients, particularly manure nutrients. Timing, rates of application, and methods of application should be part of an overall farm plan to provide adequate fertilization for crops while minimizing losses of nutrients in surface runoff and deep percolation. Manure and fertilizer management has been contracted on farms that have been signed into the program. Future efforts to contract or simply provide technical assistance for nutrient management on farms not in the program are expected to significantly reduce the loss of nutrients from fields and barnyard areas.

While some poultry manure is sold and may not be applied to cropland in the watershed, most manure produced in the watershed is applied there. One method to reduce nutrient applications is to haul the manure to an area with a shortage of nutrients. This appears particularly promising for poultry operations. Poultry manure produces over one-third of the manure nutrients in Lancaster County. Only 30 percent of Lancaster County farms have poultry operations and many of these farms have other livestock (which contribute more manure) and/or have relatively less cropland acreage to spread manure compared to livestock farms. Poultry manure is much higher in nutrient value than other manures, can be more easily dried and transported, and is typically excessive to be field- applied on the farms on which it is produced. A manure marketing program is being implemented as part of the Chesapeake Bay Program and should facilitate the movement of animal manures. For these reasons poultry farmers should be encouraged to sell or give away their manure to those who can use it to improve profits in an ecologically sound manner.

Due to costly handling and transportation, it was found that hauling dairy manure 30 to 40 miles as means of removing the nutrients from the watershed caused substantial reductions in income on a representative dairy farm. Currently, RCWP is paying the cost of manure export from one monitored site. For the optimal storage systems (uncovered, 6-month) analyzed, a 30-percent reduction in nitrogen losses caused approximately a 19-percent reduction in income when manure was hauled 40 miles. A 50- percent nitrogen-loss reduction resulted in a 46-percent loss of income. Therefore, manure hauling is an expensive method reducing nitrogen losses, and should be considered as a last alternative for controlling losses.

Other alternatives to land application of manure include: (1) direct combustion, (2) use as a substrate for methane production, (3) production of synthetic fuel, (4) refeeding the manure to livestock, and (5) using marginal land to produce biogas for energy. Power generation (first three alternatives) requires economies of scale in order to be produced profitable. Refeeding of manure causes livestock health problems if done at significant levels. Consideration of using manure to produce biomoss (wood) as a fuel source is just now beginning. Research on all five alternatives is ongoing and may provide legitimate alternatives in the future. It is apparent that a combination of nutrient management, crop management, water control management and land use management BMPs, plus some legal restraint on agricultural intensity may be needed to improve water quality to publicly acceptable levels in the Conestoga Headwaters.

Professional Reports on the Economic Evaluation

Publications

1. Young, C. Edwin, Bradley M. Crowder, James S. Shortle, and Jeffery R. Alwang. "Nurtient Management on Dairy Farms in Southeastern Pennsylvania." Journal of Soil and Water Conservation, Vol. 40, No. 6, Sept. - Oct., 1985.

2. Crowder, Bradley M., and C. Edwin Young. Modeling Agricultural Nonpoint Source Pollution for Economic Evaluation of the Conestoga Headwaters RCWP Project. Staff Report N. AGES850614. Economic Research Service, USDA, Washington, D.C., 1985, 70 pp.

3. Crowder, Bradley M., and C. Edwin Young. "Evaluating BMPs in Pennsylvania's Conestoga Headwaters Rural Clean Water Program." Proceedings: Nonpoint Pollution Abatement Symposium. Marquette University, Milwaukee, WI, 1985, pp. P-III-A-1 - P-III-A-11.

4. Alwang, Jeffery, R. "An Economic Evaluation of Alternative Manure Management Systems and Manure Hauling." Unpublished Master of Science thesis, Department of Agricultural Economics and Rural Sociology, Pennsylvania State University, 1985.

5. Crowder, Bradley M. and C. Edwin Young. "Economic Evaluation." Conestoga Headwaters Rural Clean Water Program: 1984 Progress Report. Agricultural Stabilization and Conservation Service, U.S. Department of Agriculture, Lancaster County, PA, 1984, pp. 91-137.

6. Young, C. Edwin and Bradley M. Crowder. "Economic Evaluation." Conestoga Headwaters Rural Clean Water Program: 1985 Progress Report. Agricultural Stabilization and Conservation Service, U.S. Department of Agriculture, Lancaster County, PA, 1984, pp.107-125.

7. Young, C. Edwin, Eugene Lengerich, James G. Beierlein, "The Feasibility of Using a Centralized Collection and Digestion System for Manure: The Case of Lancaster County." (In) Proceedings of Conference on Poultry Waste Conversion, (H.C. Jordan and R.E. Graves, eds.), Pennsylvania State University, University Park, PA (1984), pp. 19-26.

8. Young, C. Edwin, Jeffery R. Alwang, and Bradley M. Crowder. Alternatives for Dairy Manure Management. Staff Report No. AGES860422, Economic Research Service, USDA, Washington, D.C., 1986, 35 pp.

Presentations

1. Crowder, Bradley M. and C. Edwin Young. "Evaluating BMPs in Pennsylvania's Conestoga Headwaters Rural Clean Water Program." Presented during Nonpoint Pollution Abatement Symposium, Milwaukee, WI., April 23-25, 1985.
2. Crowder, Bradley M. and C. Edwin Young. "Modeling the Cost Effectiveness of Soil Conservation Practices for Stream Protection." Selected paper presented during the NAREA annual meetings, Amherst, MA, June 24-25, 1985.
3. Young, C. Edwin, Bradley M. Crowder, James S. Shortle, and Jeffery R. Alwang. "Nutrient Management on Dairy Farms in southeastern Pennsylvania." Selected paper presented during the AAEA annual meetings, Ames, IA, August 4-7, 1985.
4. Crowder, Bradley M. and C. Edwin Young. "The Effects of Manure Management on Field Nutrient Losses: A Modeling Approach." Selected paper presented during the AAEA annual meetings, Reno, Nevada, July 27-30, 1986.

6.0 MONITORING DESIGN AND STRATEGY[1]

The monitoring design of the Conestoga Headwaters project and the strategy used to determine the effects of agricultural BMPs on water quality are discussed in this chapter. Monitoring was conducted at three scales: the regional, small watershed, and field levels. The project was designed to compare surface- and ground-water quality before and after implementation of BMPs. The primary water-quality concerns of the project were suspended sediment, nutrients, and herbicides.

6.1 FINDINGS AND RECOMMENDATIONS

6.1.1 Experimental Design

- The experimental design should be well thought out and planned before detailed studies begin.
- Good monitoring designs allow enough time to evaluate the system over a full range of hydrologic conditions before and after implementing agricultural-activity changes. The project should be long enough to allow for water quality to reflect agricultural-activity changes.
- Only one BMP should be evaluated at a site. Combined BMPs diminish the possibility of evaluating an individual BMP, and make information gained from the study less widely applicable.
- Observing similar water-quality responses to a BMP at several different locations helps to determine cause and effect.
- BMP cause and effect studies are probably not feasible in areas much larger than a single farm because of the difficulty of implementing and monitoring agricultural-activity changes.
- Controlled study designs facilitate the interpretations of study data. Controlled designs include water-quality monitoring upstream and downstream of an agricultural-activity change, paired watersheds, or, in the case of ground water, monitoring upgradient and downgradient of an agricultural-activity change.
- Paired-watershed studies, while preferred, can be difficult to design. They require care in selection of sites so that data from the sites is comparable. To be comparable, the sites need to have similar geology, hydrologic responses, land use, and, initially, similar agricultural activities.
- Extremely wet or dry periods make interpretation of water-quality data difficult because many nutrient transport processes are controlled by precipitation. BMPs may be more or less effective in improving water quality under extremely wet or dry conditions.
- Random events, such as animal disease outbreaks (avian influenza and swine pseudo rabies), changing property ownership, and extreme precipitation events (Hurricane Gloria and others) that occurred in the Conestoga project, were not controllable but can affect a project.
- Process-oriented studies lead to an improved understanding of the transport mechanisms of agricultural chemicals and ultimately to the development of more effective BMPs.

[1] Principal contributors to this chapter were David Fishel, Patricia Lietman, Edward Koerkle, and David Hall of the U.S. Geological Survey and Mary Jo Brown of the Pennsylvania Department of Environmental Resources.

6.1.2 Site Selection

- Beneficial uses of water and related water-quality problems should be identified before BMPs are implemented or a water-quality study begins.
- An investigation which includes preliminary reconnaissance and sampling of the sources and movement of surface and ground water at potential study sites should be conducted prior to site selection. Such an investigation would reduce uncertainties in the interpretation of monitoring data.
- The initial monitoring objectives for the Pennsylvania project had too large of a scope relative to areas of BMP implementation.

6.1.3 Data Collection and Analysis

- Methods of statistical analysis should be selected at the beginning of a monitoring project. The statistical methods chosen will determine the types of data that are collected.
- Water-quality and agricultural-activity data should be collected for at least a two-year period before any BMP is implemented, in order to gain an initial understanding of the system.
- The Pennsylvania project had a flexible data-collection and analysis program. Flexibility of a monitoring design is necessary to accommodate changes indicated by preliminary data analyses, changes in protocol, and the availability of new technology. However, any monitoring strategy needs to be consistent enough to ensure proper data analyses.
- Near-stream ground-water-quality data may prove more informative than in-stream base-flow data when trying to establish relations between agricultural activities and water quality.
- Quality-control procedures must be developed and followed to ensure the accuracy and precision of any data that are collected.
- Establishing agricultural-activity records for comparison to water-quality data is difficult and time consuming. Defining the proximity of agricultural activity to water sources, determining the nutrient content of livestock manures and the portion that is available for transport to surface or ground water, and development of a system to handle highly detailed data are some of the problems that may be encountered.
- Agricultural-activity and soil-nutrient data were not as precise as water-quality data collected during the Pennsylvania project. This limited the possibilities of establishing cause and effect relations.
- Collection of agricultural-activity data is most accurate when farmers are interviewed frequently, and information verified by field inspection.
- Soil-sampling methods and sampling locations were inconsistent during the study, making data interpretation difficult.
- Information on the ammonia and the organic nitrogen content of soils in addition to data collected on soil nitrate would have been helpful in understanding the movement of nitrogen through soils.
- Monitoring of soil nutrients should include sampling of near-stream soils through which water from a monitored site may enter a stream.

6.1.4 Farmer and Interagency Cooperation

- Cooperation of the farmers is essential to the successful evaluation of BMP effectiveness. Personal preferences and financial considerations may divert farmers away from implementation goals, and thereby complicate analysis of project data.

- Coordination between agencies implementing and monitoring the agricultural-activity changes is essential to project success. Cooperation and coordination between agencies involved in the Pennsylvania project was good. However, effective coordination may be compromised by differences in project objectives and perceptions of how specific activities should be conducted. For example, one agency may evaluate the program on the number of contracts being written with farmers while another agency may evaluate the program on whether or not BMPs are being practiced according to plans.
- An ideal scientific study for evaluating changes in agricultural activities occurs when researchers have complete control of farm management.

6.2 GENERAL STRATEGY

The U.S. Geological Survey (USGS) and the Pennsylvania Department of Environmental Resources (PaDER) were responsible for developing the water-quality monitoring design and strategy that consisted of three components (fig. 6-1). The first component, the regional study area, consisted of general monitoring on a regional scale and included the entire Conestoga Headwaters RCWP Project area of 188 mi^2 (square miles). The second component involved more detailed monitoring in a small watershed of 5.8 mi^2. The third component consisted of intensive monitoring at two sites on a field scale. Field-Site 1 was 23 acres and Field-Site 2 was 48 acres. All three components were designed to compare surface- and ground-water quality before and after implementation of agricultural best-management practices (BMPs). Because excessive nutrients and erosion were identified as the major problems in the project area, the BMPs to be implemented and evaluated as part of the Conestoga Headwaters Comprehensive Monitoring and Evaluation project monitoring were nutrient management, animal-waste storage, and terracing. Nutrient management, the implementation of BMP 2 (Animal Waste Management Systems), and BMP 15 (Fertilizer Management) were especially emphasized in the monitoring components. However, other water-quality concerns of the project included the monitoring of suspended sediment and pesticides (herbicides and insecticides).

The monitoring program was designed to incorporate several monitoring strategies. The strategy for the Regional study area was to compare concentrations and discharges of suspended sediment, nutrients, and pesticides before and after implementation of all forms of BMPs. The strategy for the Small Watershed study was to compare concentrations and discharges of suspended sediment, nutrients, and pesticides before and after the implementation of nutrient management using a paired-watershed strategy and an upstream/downstream comparison strategy. The strategy for the Field-Site 1 study was to compare concentrations and discharges of suspended sediment, nutrients, and pesticides before and after the implementation of nutrient management, animal waste storage, and terracing BMPs. The strategy for the Field-Site 2 study was to compare concentrations and discharges of nutrients before and after the implementation of nutrient management.

Refinements to the monitoring strategies were made after preliminary data were collected and interpreted, and consultations were made with cooperating agencies and statisticians from the U.S. Geological Survey systems analysis group and the RCWP coordinating committee. The refinements are discussed in section 7 within the results for each component of the study.

6.3 DATA COLLECTION

6.3.1 Precipitation

Precipitation quantity and intensity data were collected at three recording precipitation gages. The gages consisted of a 13-inch plastic funnel mounted above a 6-inch plastic receiving pipe equipped with an analog digital recorder (ADR) which recorded rainfall every 5 minutes. The data were compared with long-term records from the National Oceanic and Atmospheric Administration (NOAA) stations at Morgantown and Ephrata, Pennsylvania (fig. 6-1), and missing data were estimated from the record collected at the two NOAA stations.

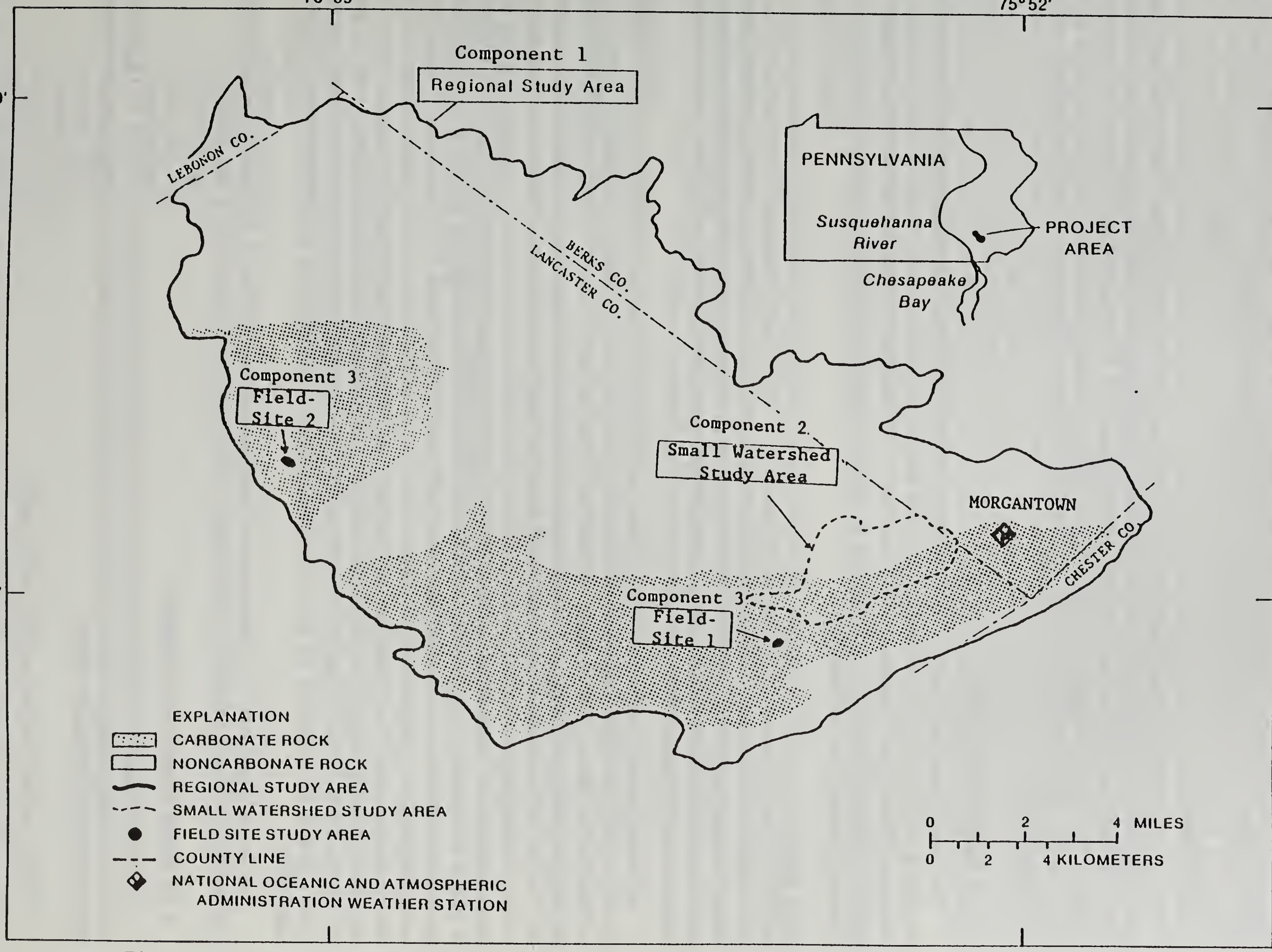


Figure 6-1.--Regional Study area (Component 1), Small Watershed (Component 2), Field Sites (Component 3), National Oceanic and Atmospheric Administration station locations and general geology.

Precipitation samples were collected one to three times yearly using a 13-inch glass funnel to collect precipitation into a glass jar inside a cooler. Ice in the cooler was used to keep the rainwater at 4 °C (39 °F) until the sample was preserved and analyzed for nitrogen and phosphorus.

6.3.2 Manure

Manure samples were collected periodically when manure was being applied onto fields. The samples were collected from agitated manure pits and storage facilities, and livestock areas, and represent manure applied to the fields. The manure samples were analyzed by A & L Eastern Laboratories, Inc. in Richmond, Virginia. The manure-nutrient analyses were used to develop nutrient management plans by the Pennsylvania State University, Cooperative Extension Service, and the nutrient budgets by the U.S. Geological Survey.

6.3.3 Agricultural Activities

The Agricultural Stabilization and Conservation Service (ASCS) collected agricultural-activity data in the spring and the fall from farmers in the Small Watershed, and farmers at the field sites provided U. S. Geological Survey field personnel with data every 2 to 4 weeks. Agricultural-activity data included the amount, time, and location of applications of manure, commercial fertilizer, pesticides, and the time of plowing, planting, and harvesting.

6.3.4 Soils

Soil samples collected during the project were analyzed for two types of nutrients: soluble nutrients (nitrate nitrogen and soluble phosphorus) and plant-available phosphorus. The soil-nutrient analyses were taken into consideration when nutrient-management plans were developed for farms in the Nutrient-Management Subbasin of the Small Watershed and at Field-Sites 1 and 2.

Soil samples analyzed for soluble nutrients were collected at the Small Watershed and the field sites. These samples were collected by the Pennsylvania State University, College of Agronomy. Samples were collected in the spring prior to major applications of manure and commercial fertilizer, in the summer (at the field sites only), and the in fall immediately after harvesting of crops. Samples were taken from the top 4 ft (feet) of soil (occasionally from the top 8 ft) in the spring and fall using a tractor-mounted, deep-soil probe. Soil sampling was usually limited to the top 4 ft as this was considered the maximum depth of the root zone for corn, which is the predominant crop in the study area. Samples were taken from the top 2 ft of soil in the summer by hand using a soil probe. The summer sampling was limited to 2 ft because crop growth prevented access to the sample location with the tractor-mounted, deep-soil probe. The soil samples were composites of three cores of soil taken to either the 4 or 2 ft depth at each location. Soil samples were divide into segments. The 4-ft samples were initially separated into 0 to 8, 8 to 24, 24 to 36, and 36 to 48 inch segments. Midway through the project the samples were separated into 3 segments, 0 to 8, 8 to 24, and 24 to 48 inches, rather than 4 segments. The 2-ft samples were separated into 0 to 8 and 8 to 24 inch segments. Each segment was analyzed by the Pennsylvania State University, Soils and Environmental Chemistry Laboratory.

Soil samples analyzed for plant-available phosphorus were collected at both field sites by Penn State Cooperative Extension personnel. These samples were collected by hand using a soil probe.

6.3.5 Water Quantity and Quality

Specific information for each component of the study are given in sections 6.7, 6.8, 6.9, and 6.10. Details of the monitoring strategy, including methods of data collection and analysis and study-area characteristics are described by Chichester (1988).

6.3.5.1 Surface-water quantity and quality

Stream stage and field runoff was recorded continuously with a graphic recorder and an analog digital recorder (ADR). V-notch weirs were installed in stream channels immediately downstream from the

continuous-record stations in the Small Watershed. The weirs created pools during periods of low flow so that accurate gage-heights could be recorded, and to stabilize the stream channels. Streamflow measurements were made using methods described by Buchanan and Somers (1968, 1969). Stream stages were converted to streamflow using methods described by Carter and Davidian (1968). At the field sites, runoff was routed to one location through a Parshall flume, where runoff stage was recorded. A standard flume rating was field checked and modified for low flow to convert gage-height record to streamflow. Base-flow water-quality samples were collected at the notch of the weir where the best mixing occurred. Stormflow samples were collected with float/stage triggered PS-69 automatic samplers, modified with refrigerator units to chill samples to 4°C (39°F). Perforated intakes for the automatic samplers were positioned in the centroid of flow in the stream or Parshall flume to assure collection of representative samples. Depth-integrated manual samples were also collected to insure that the automatic samples were representative of the stream cross-section. As each sample was collected by the automatic sampler an event marker was triggered to mark the graphic recorder so that the time of collection could be determined. Stormflow samples were analyzed as discrete samples. Concentrations of each constituent were plotted and hydrographs were drawn. The total stormflow load of each constituent was computed using streamflow and concentration-integration techniques described by Porterfield (1972).

6.3.5.2 Ground-water quantity and quality

Ground-water levels were measured manually with a steel tape and automatically with continuous-graphic recorders.

Ground-water-quality samples were collected at the maximum water-bearing zone in the well using methods described by Lietman and others (1989), or by pumping the well and then using a bailer according to methods described by Classen (1982). Samples were also collected from spring overflows. Domestic wells were sampled by engaging the pump until constant temperatures and specific conductance was measured. The water sample was then taken directly from the taps (all water-treatment systems were bypassed).

6.4 ANALYSES

6.4.1 Chemical

Surface- and ground-water samples, and precipitation samples were analyzed for some or all of the following physical or chemical parameters. Reporting units are in parenthesis.

- Water temperature (°C)
- Specific conductance (µS/cm at 25 degrees Celsius)
- Suspended sediment (mg/L)
- Total and dissolved
    - Ammonia (mg/L)
    - Ammonia + organic nitrogen (mg/L)
    - Nitrite nitrogen (mg/L)
    - Nitrate + nitrite nitrogen (mg/L)
    - Phosphorus (mg/L)
- Dissolved
    - Calcium (mg/L)
    - Magnesium (mg/L)
    - Sodium (mg/L)
    - Potassium (mg/L)
    - Sulfate (mg/L)
    - Chloride (mg/L)
- Total
    - Alachlor (µg/L)
    - Atrazine (µg/L)
    - Cyanazine (µg/L)
    - Metolachlor (µg/L)
    - Propazine (µg/L)
    - Simazine (µg/L)
    - Toxaphene (µg/L)

Water temperature and specific conductance were measured in the field. Suspended-sediment and particle-size samples were analyzed at the U.S. Geological Survey Sediment Laboratory in Harrisburg, Pa., by methods described by Guy (1969). Water-quality samples were analyzed by the Pennsylvania Department of Environmental Resources (PaDER), Bureau of Laboratories. Total concentrations of chemical constituents were determined on unfiltered samples, and concentrations of dissolved constituents were determined for samples filtered through a 0.45-micron filter. All water-quality samples were preserved by chilling them to 4°C (39°F) from the time of collection to analysis. Nutrient samples were preserved with mercuric chloride. Nutrients and major ions were analyzed using methods described by Skougstad and others (1979), and pesticides were analyzed using the modified USEPA proposed method 608 (1985).

Soil samples were analyzed for soluble nitrate-nitrogen and soluble phosphorus by the Pennsylvania State University, Soils and Environmental Chemistry Laboratory, according to methods by Corey (1977) and the USEPA (1979). Soil samples collected by the Pennsylvania State University Cooperative Extension Agency were analyzed for Bray-1 phosphorus by the Merkle Laboratory at Pennsylvania State University. The Bray-1 analysis, a common test for plant-available phosphorus, is approved in Pennsylvania for determining agronomic fertilizer recommendations incorporated into the nutrient-management plans (Thomas Juengst, Pennsylvania Department of Environmental Resources, Bureau of Soil and Water Conservation, written communication, 1991).

Manure samples were analyzed by A&L Eastern Agricultural Laboratories, Inc., in Richmond, Va., for nitrogen, phosphorus, and moisture content using methods by Williams (1984).

6.4.2 Statistical

Nonparametric and parametric statistical procedures were used for the in-depth analysis of the water-quality data. Nonparametric analyses included the Seasonal Kendall test for trend, the Wilcoxon rank-sum test, and the Mann Whitney rank-sum test. Parametric linear regression analyses were evaluated using F- and t-tests. Statistical procedures were performed with statistical packages from the Statistical Analysis System (SAS) Institute, Inc. (1982a, 1982b), P-STAT, Inc. (1986), and SYSTAT, Inc. (Wilkenson, 1988), and modifications made to the packages of Crawford and others (1983), and Hirsch (oral communication, 1989).

6.5 QUALITY ASSURANCE

A quality-assurance plan was developed and maintained throughout the project. The quality-assurance plan was with the PaDER, Bureau of Laboratories, where water-phase nutrient and pesticide samples were analyzed. The quality-assurance plan is discussed in detail in Appendix D.

6.6 DATA MANAGEMENT

Most of the water-quality data collected during the project are stored in the USEPA STORET and the USGS WATSTORE data retrieval systems. STORET and WATSTORE retrieval codes are given in Appendix E. Both data bases use the same station identification numbers. Water-quality, streamflow, and ground-water-level data are published in annual USGS Water Resources Data Reports (1983-90).

Water-quality data that is not in the STORET and WATSTORE systems are stored in either the USGS office in Lemoyne, Pa., or the PaDER office in Harrisburg, Pa. This includes data from quality-assurance sampling and miscellaneous samples from locations which were not assigned official USGS station identification numbers. In addition, precipitation, soil, and agricultural-activity data are on file at the USGS office in Lemoyne, Pa.

6.7 REGIONAL STUDY AREA

6.7.1 Location

The Regional Study area encompassed the entire Conestoga Headwaters RCWP Project area. This 188-mi^2 area is located in southeastern Pennsylvania, primarily in Lancaster County, with small portions in Chester, Berks, and Lebanon Counties (figure 6-1).

6.7.2 General Strategy

The monitoring strategy for the Regional Study area is shown in table 6-1. The water-quality monitoring schedule was to monitor for three one-year phases: (1) a pre-BMP phase, (2) an early post-BMP phase, and (3) a later post-BMP phase. Because few BMPs were implemented over the large study area, the overall water quality was not expected to change within the time frame of the project. Therefore, only the pre-BMP period monitoring was conducted. As authorized by the RCWP National Coordinating Committee, the money allocated for the later post-BMP period monitoring was used for monitoring at the Small Watershed and Field-Sites 1 and 2.

Surface and ground water, fish, and benthic macroinvertebrates were sampled in the Regional Study area component. Water-quality monitoring, primarily for nutrients and pesticides, was conducted at 43 ground-water sites and 4 surface-water sites in the 188-mi^2 RCWP Project area (fig. 6-2). The fish community was surveyed at four locations in October 1982 by the Pennsylvania Fish Commission. Qualitative and quantitative sampling of the benthic macroinvertebrate community was conducted in April 1982, October 1988, and May 1989 at seven locations, including three of the locations where the fish community was sampled.

6.7.3 Land Use

The Regional Study area is primarily a rural, agricultural area with small towns and villages. Estimates of land use in the Regional Study area are listed below (Leon Ressler and Robert Anderson, Penn State Extension Service, oral communication, 1989).

Table 6-1.--Monitoring strategy for the Regional Study area

SCHEDULE

April 1982 - September 1983	Pre-BMP period
CANCELLED	Post-BMP period

APPROACH

To determine the effects of all forms of BMPs, pre-BMP and post-BMP concentrations and discharges of suspended sediment, nutrients, and pesticides, were to be compared.

DATA COLLECTION

Location	Constituent or parameter	Frequency
2 Continuous-record stations	Suspended sediment, nutrients, and pesticides	Monthly base flow and major storms
2 Partial-record stations	Suspended sediment, nutrients, and pesticides	Monthly base flow
42 Wells and 1 spring[1]	Nutrients	4 times per year
	Pesticides	3 times per year
3 Precipitation stations	Precipitation intensity, total accumulation	5 minute intervals

[1] The initial ground-water network was comprised of 77 wells and 1 spring but was reduced to 42 wells and 1 spring in March 1983.

Land use	Acres
Woodland	40,000
Urban	7,000
Agriculture	
carbonate soils	27,000
noncarbonate soils	36,000
Total	110,000

6.7.4 Geology

The RCWP Project area lies in two physiographic provinces (Berg and others, 1989). A small part of the northeastern portion of the project lies in the Reading Prong section of the New England province underlain by granitic gneiss, granodiorite, and quartzite. The remainder of the project area is in two sections of the Piedmont province. Part of the northeastern portion of the project area is in the Gettysburg-Newark Lowland section underlain by conglomerate, sandstone, shale, and diabase. The southwestern portion of the study area is in the Piedmont Lowland section underlain mainly by carbonate rocks.

6.7.5 Soils

Soils in the Regional Study area are primarily of the Duffield, Hagerstown, Ungers, Bucks, and Lansdale series with lesser amounts of the Manor, Chester, Glenelg, Bedington, and Clymer series (United States Department of Agriculture, 1985). The soils are nearly level to very steep, and well drained. Soils from the Duffield and Hagerstown series are formed in residuum from carbonate rock. The soils from the remaining series are formed in the residuum from siltstone, conglomerate, shale, sandstone, and metamorphic rocks.

6.7.6 Data Collection

6.7.6.1 Precipitation

Precipitation-quantity and -intensity data were collected at three stations in the Regional Study area (fig. 6-2). Following the postponement of the post-BMP monitoring at the Regional Study area, one station was moved to the Field-Site 2 study area. The remaining two stations continued operating and provided data for the Small Watershed and the Field-Site 1 study area.

6.7.6.2 Agricultural activities

Because few BMPs were implemented over the Regional Study area during the study period, and the overall water quality was not expected to change within the time frame of the project, only limited agricultural-activity data were compiled for use with water-quality data analysis for the large study area. Instead, data collection was concentrated in the Small Watershed and Field-Sites 1 and 2.

6.7.6.3 Surface-water quantity and quality

Surface-water-quantity and -quality data were collected at a network of four stations draining about 75 percent of the 188-mi^2 area of the Conestoga Headwaters (fig. 6-2 and table 6-2). Two of the stations were continuous-record stations: Conestoga River near Terre Hill, Pa., and Little Conestoga Creek near Churchtown, Pa., and two were partial-record stations: Muddy Creek near Martindale, Pa., and Cocalico Creek near Ephrata, Pa. About half of the drainage areas of the continuous-record stations were underlain by carbonate rock. Muddy and Cocalico Creeks drained areas underlain primarily by noncarbonate rock (99.7 and 89 percent, respectively).

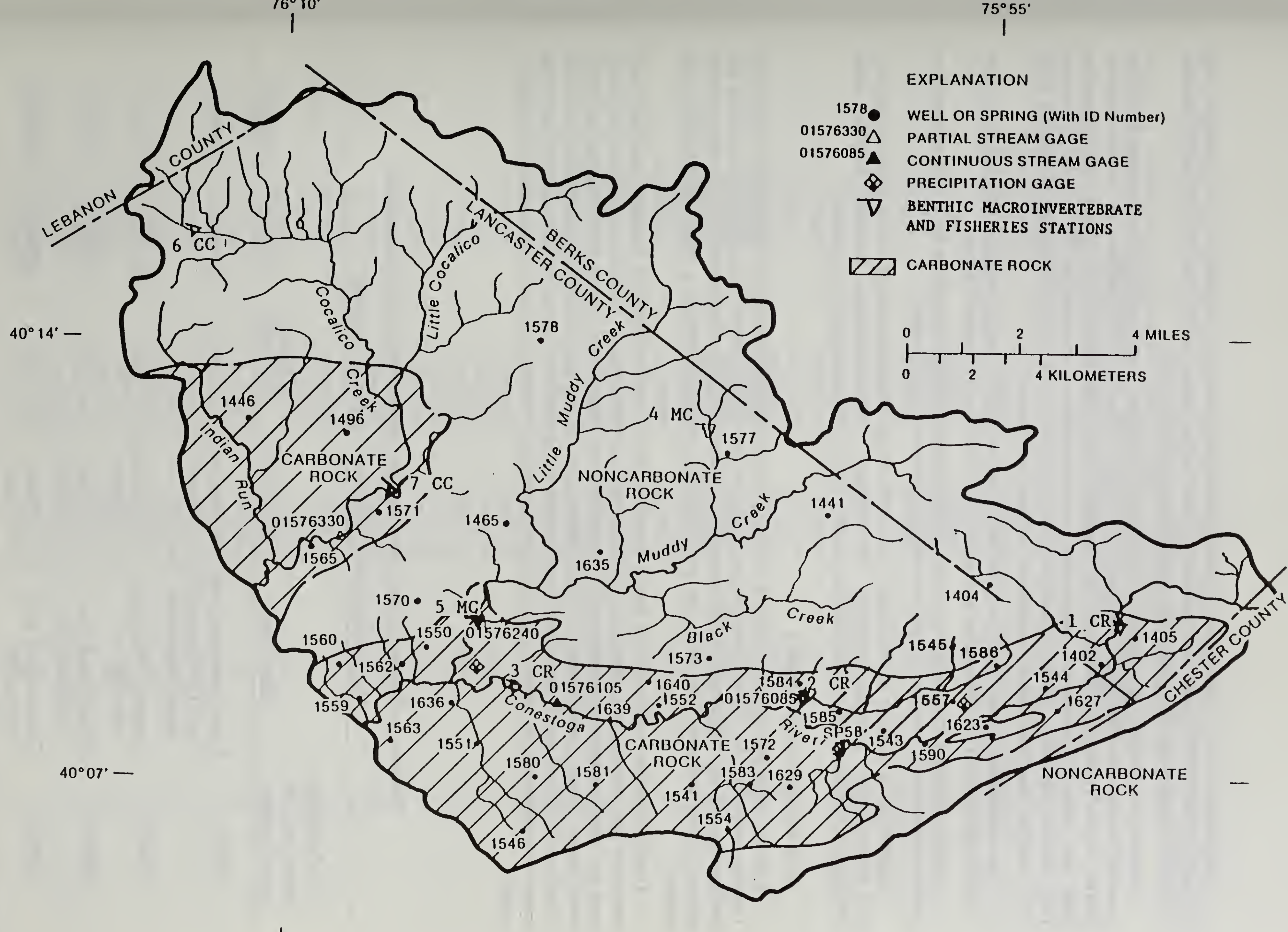


Figure 6-2.--Regional Study area surface-water, ground-water, benthic-macroinvertebrate, fisheries, precipitation station locations, and general geology.

Data collected at the Conestoga River near Terre Hill included daily streamflow from November 1981 through September 1983, suspended-sediment concentrations during storms from May through September 1983, and monthly base-flow data from April 1982 through April 1983.

Data collected at the Little Conestoga Creek near Churchtown were more extensive because the station remained in operation throughout the project, first as part of the Regional Study area, and subsequently as part of the Small watershed study area. Daily streamflow was measured from June 1982 through September 1989. Daily suspended-sediment concentration data were collected from August 1982 through November 1983. Monthly base-flow and storm samples were collected from August 1982 through September 1989. Storm samples were analyzed for suspended sediment and nutrients.

Data collected at Muddy Creek and Cocalico Creek included monthly base-flow samples from April 1982 through March 1983. Streamflow was measured at the time of sample collection.

Base-flow samples at all four stations, for samples collected through September 1983, were analyzed for specific conductance, temperature, pH, major ions, nutrients, and pesticides.

Bacteriological samples were collected during the fall of 1982 and spring of 1983 at all of the surface- and ground-water sampling locations. The sampling was discontinued, however, because some uncharacteristic and unidentifiable colonies were observed on culture plates for bacteria.

6.7.6.4 Ground-water quality

Ground-water quantity and quality data were collected in September 1982 at a network of 77 wells and 1 spring located in the 188-mi^2 area of the Conestoga River Headwaters. This network of wells in the shallow ground-water system (100-250 feet deep) was then reduced to a final network of 42 wells and one spring (fig. 6-2 and table 6-3). All of the wells and the spring were used as a source of domestic-water supply.

Thirty-two of the wells and one spring were distributed over one-third of the study area and were underlain by carbonate rock (table 6-3). The other wells were distributed over the remainder of the study area, and were underlain predominantly by sandstone and shale. Thirty-one of the wells and one spring were located in agricultural areas; 27 of the wells and one spring were underlain by carbonate rock. The collection of ground-water data was concentrated in the agricultural and carbonate areas because those areas were determined in other studies to be most susceptible to nonpoint-source contamination of ground water.

Table 6-2.--Regional Study area surface-water data-collection stations

[mi^2, square mile; °, degree; ', minute; ", second]

U.S. Geological Survey identification number	Station name	Station type	Drainage area (mi^2)	Latitude	Longitude
01576085	Little Conestoga Creek near Churchtown, Pa. (Small Watershed)	Continuous record	5.82	40°08'41"	75°59'20"
01576105	Conestoga River near Terre Hill, Pa.	Continuous record	49	40°08'44"	76°04'41"
01576240	Muddy Creek near Martindale, Pa.	Partial record	49	40°10'12"	76°06'21"
01576330	Cocalico Creek near Ephrata, Pa.	Partial record	43	40°11'39"	76°09'09"

Table 6-3.--Regional Study area ground-water data-collection locations

[A, agricultural; NA, nonagricultural; C, carbonate; NC, noncarbonate; °, degree; ', minute; ", second]

U.S. Geological Survey identification number	Latitude	Longitude	Land use	Rock type
BE 1402	40°08'51"	75°53'08"	A	C
BE 1404	40°10'12"	75°55'29"	NA	NC
BE 1405	40°09'13"	75°52'23"	A	C
LN 1441	40°11'35"	75°58'51"	NA	NC
LN 1446	40°13'38"	76°11'07"	A	C
LN 1465	40°11'42"	76°05'47"	A	NC
LN 1496	40°13'18"	76°08'59"	A	C
LN 1541	40°07'15"	76°01'55"	NA	C
LN 1543	40°07'58"	75°57'49"	NA	C
LN 1544	40°08'34"	75°54'16"	A	C
LN 1545	40°09'20"	75°56'13"	NA	NC
LN 1546	40°06'37"	76°05'32"	A	C
LN 1550	40°09'08"	76°07'28"	A	C
LN 1551	40°08'08"	76°06'24"	A	C
LN 1552	40°08'33"	76°02'36"	A	C
LN 1554	40°06'28"	76°01'13"	A	C
LN 1557	40°08'28"	75°56'16"	NA	C
LN 1559	40°08'55"	76°08'57"	A	C
LN 1560	40°09'32"	76°09'25"	A	C
LN 1562	40°09'27"	76°08'01"	A	C
LN 1563	40°08'13"	76°08'19"	A	C
LN 1565	40°11'27"	76°09'49"	NA	C
LN 1570	40°10'32"	76°07'39"	NA	NC
LN 1571	40°11'57"	76°08'27"	A	C
LN 1572	40°07'34"	76°00'15"	NA	C
LN 1573	40°09'18"	76°01'30"	A	NC
LN 1577	40°12'40"	76°00'53"	A	NC
LN 1578	40°14'36"	76°04'51"	NA	NC
LN 1580	40°07'30"	76°05'16"	A	C
LN 1581	40°07'27"	76°03'56"	A	C
LN 1583	40°07'12"	76°00'45"	A	C
LN 1584	40°08'47"	75°59'35"	A	C
LN 1585	40°08'23"	75°58'48"	A	C
LN 1586	40°08'53"	75°55'21"	A	C
LN 1590	40°07'44"	75°56'56"	A	C
LN 1623	40°07'57"	75°55'38"	NA	NC
LN 1627	40°08'09"	75°54'06"	A	C
LN 1629	40°07'02"	75°59'50"	A	C
LN 1635	40°11'09"	76°03'42"	A	NC
LN 1636	40°08'48"	76°06'53"	A	C
LN 1639	40°08'34"	76°03'30"	A	C
LN 1640	40°08'58"	76°02'48"	A	C
LN SP58	40°07'44"	75°58'39"	A	C

Data were collected at the ground-water network four times during the pre-BMP phase: during the Fall of 1982, and during the Spring, Summer, and Fall of 1983. Depth to water level was measured and samples were collected and analyzed for specific conductance, water temperature, pH, nutrients, major ions, and pesticides during each sampling except in the Fall of 1982 when no pesticide data were collected. A summary of the ground-water nutrient and herbicide data was reported by Fishel and Lietman (1986).

6.7.6.5 Fish

Standardized fish-collection methods were used. Electrofishing was conducted using a boat-towed generator except at one station where, because of the small size of the stream, a backpack unit was used. Game fish populations were estimated using the Zippen Removal Method (Journal of Wildlife Management, 1965). Locations of electrofishing were at or near the surface-water network stations (table 6-4). Relative abundance of nongame fish were estimated at three locations - Conestoga River near Terre Hill on October 20, 1983, Muddy Creek near Martindale on October 21, 1982, and 1.0 mile downstream from Cocalico Creek near Ephrata on October 28, 1982, and counted at the fourth location, Little Conestoga Creek near Churchtown, on August 20, 1982.

6.7.6.6 Benthic macroinvertebrates

A benthic-macroinvertebrate survey was conducted using the procedures in PaDER's "Standardized Biological Field Collection Methods" (1988). Samples were collected in April 1982, October 1988, and May 1989, at ten stations (table 6-5). Water-quality samples were collected by PaDER personnel along with samples for benthic macroinvertebrates.

A summary of the three benthic-macroinvertebrate survey protocols is as follows:

- In 1982, sampling was conducted from April 14 to April 19 at seven sites using Surber and kick screen samplers. Results were presented in both a qualitative (presence and relative abundance) and quantitative (Surber) form.
- In 1988, sampling was conducted October 25 and 26 at ten sites using Surber and kick screen samplers. Results were presented in a qualitative form (presence and relative abundance) for all stations and in a quantitative (Surber) form for three stations.

Table 6-4.--Regional Study area fish survey stations

[m, meter; ha, hectare; min, minute]

Station name	Station location	Station length	Station area	Electrofishing time	
Little Conestoga Creek near Churchtown, Pa. (Small Watershed)	T-773 bridge	800 m	0.108 ha	pass 1 pass 2 pass 3	75 min 49 min 35 min
Conestoga River near Terre Hill, Pa.	240 m downstream of T 810 bridge	300 m	0.357 ha		84 min
Muddy Creek near Martindale, Pa.	38 m downstream of T 674 bridge	300 m	0.303 ha	pass 1 pass 2 pass 3	62 min 56 min 39 min
Cocalico Creek near Ephrata, Pa.	37 m upstream of T 941 bridge	300 m	0.348 ha	pass 1 pass 2 pass 3	60 min 42 min 31 min

Table 6-5.--Regional Study area benthic-macroinvertebrate survey stations

[°, degree; ', minute; ", second]

PaDER or USGS station identification		Station location	Latitude	Longitude
PaDER	1CR	Conestoga River near Morgantown, in small pasture	40°09'42"	75°52'53"
USGS	Site 1	Little Conestoga Creek at Site 1, near Morgantown	40°09'22"	75°55'14"
USGS	Site 3A	Little Conestoga Creek at Site 3A, near Morgantown	40°08'47"	75°55'37"
USGS	Site 9	Unnamed tributary at Site 9, at Churchtown	40°08'20"	75°58'14"
PaDER	2CR	Conestoga River near Terre Hill	40°08'39"	76°00'37"
PaDER	3CR	Conestoga River at Martindale	40°08'42"	76°04'50"
PaDER	4MC	Muddy Creek near Bowmansville, adjacent to trailer park	40°12'37"	76°01'12"
PaDER	5MC	Muddy Creek at Frysville	40°10'16"	76°06'22"
PaDER	6CC	Cocalico Creek at Cocalico House	40°16'42"	76°12'17"
PaDER	7CC	Cocalico Creek near Ephrata	40°12'14"	76°08'09"

In 1989, the sampling was conducted May 15, 30, and 31 at ten sites using Surber and kick screen samplers. The data were presented in a qualitative (presence and relative abundance) and quantitative (Surber) form.

6.7.7 Data Analysis

The Regional Study area data analysis included the use of maps, tables listing descriptive statistics, and graphs of data over time. Data were grouped according to land use, underlying rock type, and season to describe the hydrologic responses of the ground water and surface water to various inputs affecting the water quality. Because data were not collected following the implementation of BMPs, comparative statistics were not generated.

6.8 SMALL WATERSHED STUDY AREA

6.8.1 Location and Description

The 5.8 mi^2 Small Watershed study area is located in the eastern portion of the Regional Study area in Caernarvon Townships, in Berks and Lancaster Counties (figures 6-1 and 6-3). The general shape of watershed is long and narrow; it is about 4.8 mi long and 2.3 mi wide at its widest point. The Little Conestoga Creek drains the watershed and discharges in a southerly direction until reaching Site 2A and then abruptly changes direction to the west.

6.8.2 General Strategy

The monitoring strategy for the Small Watershed study area is shown in table 6-6. The Small Watershed study area is being used to determine the effects of implementing the nutrient management BMP on surface- and ground-water quality.

Water quantity and quality, agricultural activity, soil chemistry, fish, and benthic macroinvertebrate data were collected in the 2-year period prior to the implementation of the BMP (April 1984 through March 1986 - pre-BMP period), and 3.5 years during the implementation of nutrient management (April 1986 through September 1989 - post-BMP period) for the RCWP program. Monitoring of the Small Watershed is being continued by the USGS in cooperation with the PaDER, Bureau of Soil and Water Conservation as part of the Chesapeake Bay Program.

Within the Small Watershed two subbasins were monitored to help characterize water quality and to better determine the effects of nutrient management on water quality. In the eastern part of the Small Watershed, a 1.42-mi subbasin was designated the Nutrient-Management Subbasin. In this area, a high degree of cooperation and implementation of nutrient management was expected (13 of 17 farmers participated). A concentrated effort was made to collect surface-water data in the Nutrient-Management Subbasin. In the northwestern part of the Small Watershed, a 1.43-mi^2 subbasin was designated the Nonnutrient-Management Subbasin. In the Nonnutrient-Management Subbasin, few if any changes in farming practices were expected, and as a result, few water-quality changes were expected. Together, these two subbasins were called the Paired-Subbasins.

6.8.3 Land Use

The predominant land use in the Small Watershed is agricultural; as shown below, 76 percent of the land in the Small Watershed and 78 percent of the land in the Nutrient-Management Subbasin is agricultural land.

Percentages of land area (based on USDA aerial photographs)

	Small Watershed	Nutrient-Management Subbasin	Nonnutrient Management Subbasin
Agriculture	68	78	59
Woodland	24	21	40
Urban	8	1	1

Most of the farms are small (less than 100 acres), owner-operated and raise both livestock and field crops. Residential land use is concentrated along the southern boundary of the study area in the village of Churchtown, and nonagricultural housing is scattered throughout the study area.

The Nutrient-Management Subbasin contains all or parts of 17 farms (fig. 6-4). Farmers from 13 of these farms worked closely with the various agencies involved in the RCWP project and provide detailed information on their agricultural activities. Agricultural activity data included crop acreage, yields, animal density, manure export, and applications of manure, commercial fertilizer, and pesticides.

The Nonnutrient-Management Subbasin contains all or parts of 14 farms (fig. 6-4). Initial surveys made in this subbasin indicated few of the farmers were interested in implementing BMPs. However, as part of the extended project, they are supplying general agricultural-activity data to USDA, Agricultural Stabilization and Conservation Service personnel.

6.8.4 Geology

The Small Watershed lies in two sections of the Piedmont physiographic province which transects Lancaster and Berks counties (Berg and others, 1989). The northern half of the Small Watershed is in the Gettysburg-Newark Lowland section and is underlain by conglomerate, sandstone, shale, and diabase of Triassic age. This section is characterized by broad highlands and ridges. The southern half of the watershed is in the Piedmont Lowland section, and is also referred to as the Conestoga Valley section. This section is underlain by carbonate rocks of the Buffalo Springs and Stonehenge Formations of Cambrian and Ordovician age, respectively, and contrasts the broad highlands and ridges with rolling lowlands.

Table 6-6.--Monitoring strategy for the Small Watershed study area

SCHEDULE

April 1984 - March 1986	Pre-BMP period
April 1986 - September 1989	Post-BMP period (RCWP program)

APPROACH

To determine the effects of nutrient management, pre-BMP and post-BMP concentrations and discharges of suspended sediment, nutrients, and pesticides were compared and a paired-subbasin comparison was conducted. Land-use data were used to interpret source of any changes.

DATA COLLECTION

Location	Constituent or parameter	Frequency
2 Continuous-record stations	Suspended sediment and nutrients	Monthly base flow and major storms
	Pesticides	Monthly during growing season
5 Partial-record stations (2 stations discontinued October 1984)	Suspended sediment, nutrients, and pesticides (at 1 station)	Monthly base flow
6 Wells and 2 springs (discontinued November 1987)	Nutrients	3 times per year
7 Soil-sample locations	Nutrients	Spring and fall
1 Precipitation station	Precipitation intensity and total accumulation	5-minute intervals
13 Farms	Agricultural activity	Spring and fall

6.8.5 Soils

Soils in the Small Watershed are of three compositions: noncarbonate, carbonate, or alluvial, and are all fine to medium textured and well drained. The major noncarbonate soils are of the Brecknock, Bucks, and Unger series, whereas the minor noncarbonate soils are of the Manor, Chester, and Glenelg series (U.S. Department of Agriculture, 1985). The alluvial soils of the Rowland and Readington series also were formed from noncarbonate residuum, but are greater than 20 in. deep and are located along the streambanks and in the flood plains. The major carbonate soils are of the Duffield and Hagerstown series, and smaller areas are of the Clarksburg and Nolin Series. Most of the carbonate soil series are cited as prime farm land in the Lancaster County Soil Survey (U.S. Department of Agriculture, 1985).

Soils in the Small Watershed and the Nutrient-Management Subbasin are proportioned similarly among noncarbonate, carbonate, and alluvial soils, as shown below. The Nonnutrient-Management Subbasin, however, has a higher percentage of noncarbonate soils than the Nutrient-Management Subbasin.

Soil composition	Small Watershed	Nutrient-Management Subbasin	Nonnutrient-Management Subbasin
	Percentages (based on USDA soil surveys)		
Noncarbonate	47	50	71
Carbonate	41	36	18
Alluvial	12	14	11

6.8.6 Data Collection

6.8.6.1 Precipitation

Precipitation quantity and intensity data were collected near the southern boundary of the Small Watershed (fig. 6-3). The precipitation gage recorded accumulated precipitation at 5-minute intervals and was installed in mid-October 1982. Precipitation data were processed and stored in a computer data file at the USGS office in Lemoyne, Pa. so that data analysis could be performed, and comparisons could be made with data collected at the National Oceanic and Atmospheric Administration precipitation station at Morgantown, Pa.

6.8.6.2 Agricultural activities

Agricultural-activity data were tabulated from daily journals kept by the farmers. Data from 13 of the 16 farmers (fig. 6-4) in the Nutrient-Management Subbasin were collected by Omar Brubaker of the USDA-ASCS, and compiled and tabulated by USGS. Of the two farms at which no agricultural-activity data were collected, one represented 9 percent of the Nutrient-Management Subbasin, and visual inspection indicated that the farm was operated as a typical farm within the subbasin. The other farm comprised less than 1 percent of the subbasin and was operated without the use of commercial fertilizers or pesticides.

Agricultural-activity data that included crop acreage, yields, animal type and density, manure export, and applications of manure, commercial fertilizer, and pesticides were collected from cooperating farmers. Little agricultural activity data were collected from the Nonnutrient-Management Subbasin; because the farmers in that subbasin were not interested in BMPs, for experimental control it was hoped that they would continue the same farming practices as they had prior to the beginning of the study.

Field acreage was determined by measurement of aerial photographs and by field inspections each year. Agricultural-activity data are stored in a computer data file in the USGS office in Lemoyne, Pennsylvania, and annual statistical summaries were produced by farm and season. The amount of manure produced by livestock in the Nutrient-Management Subbasin was calculated and compared to application data provided by farmers to verify the data. The amount of nutrients from manure applied to fields in the Nutrient-Management Subbasin was calculated by multiplying the typical concentrations of nitrogen and phosphorus supplied by ASCS for livestock and poultry manure by the application quantities provided by the farmers.

6.8.6.3 Soils

Soil samples were collected to attempt to determine the amount of excess nutrients available for leaching to the ground water, and because concentrations of nutrients in soils were expected to decrease in response to a decrease in nutrient applications, prior to a decrease in surface water.

Soil samples were collected from fields in the carbonate valley section of the study area. Soil samples were initially collected at 13 locations within the Nutrient-Management Subbasin in November 1984; sampling was then reduced to seven locations (farms A, E, F, G, H, I, and O). Sampling was further reduced to four locations (farms D, F, H, and M) in July 1987 to reduce monitoring costs and due to inconsistencies over time in location of sampling sites. The soil samples were collected in the spring prior to planting and

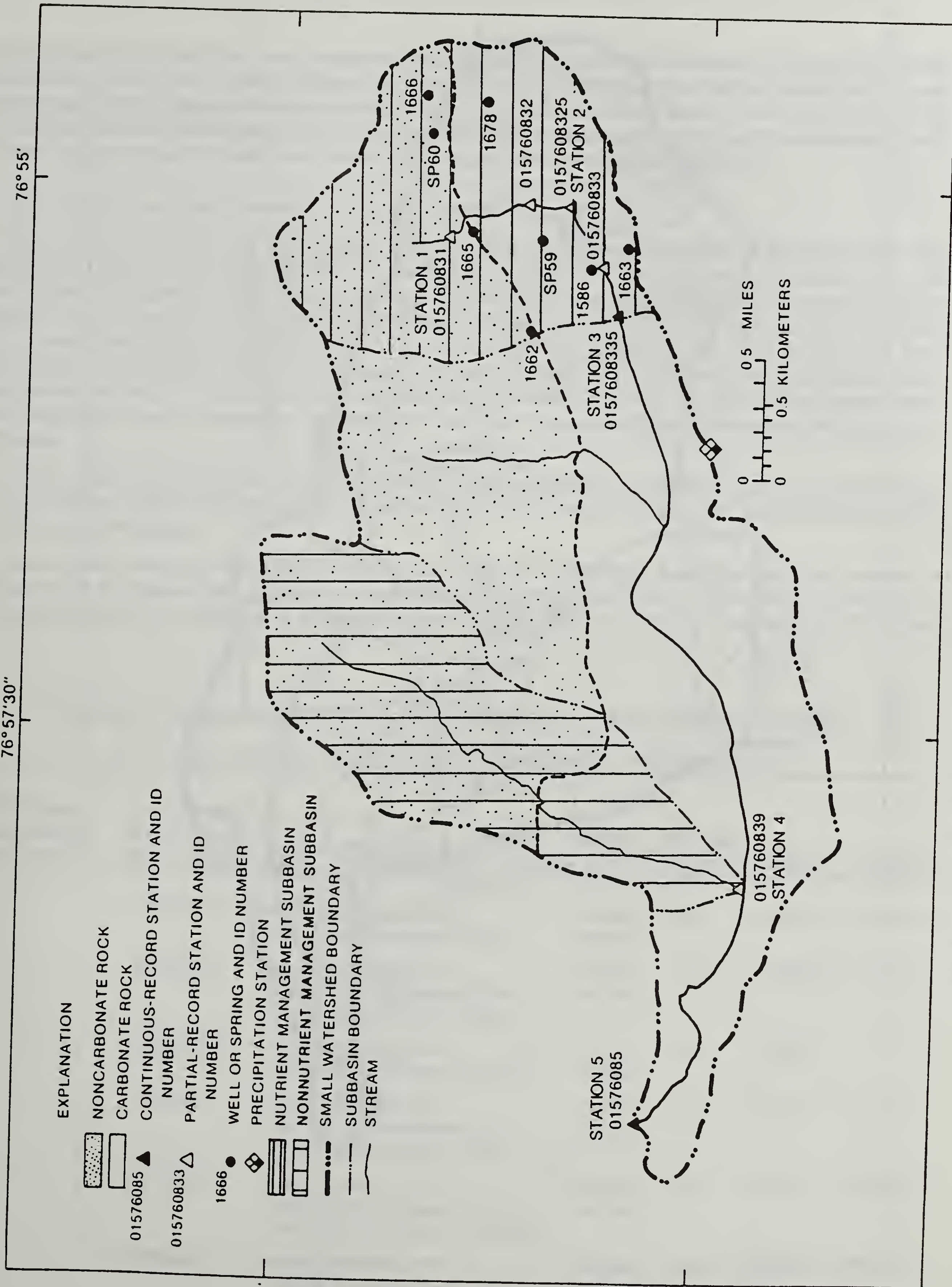


Figure 6-3.--Small Watershed surface-water, ground-water, precipitation station locations, and general geology.

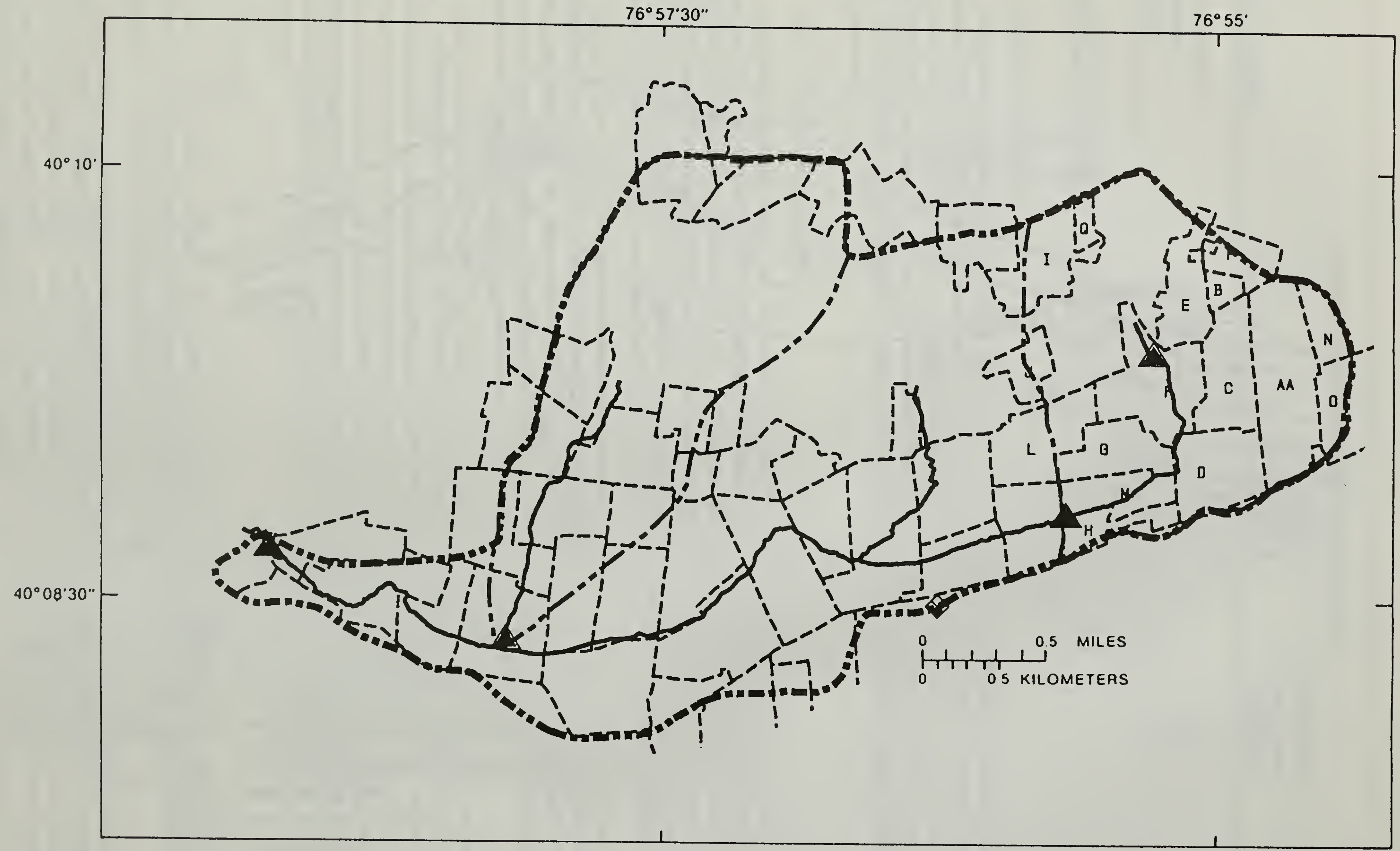


Figure 6-4.--Farm locations in the Nutrient-Management Subbasin and the entire Small Watershed

fertilizing, and in the fall after corn was harvested. Soil samples were collected from the top 4 feet of soil; samples from farms D and M were collected to a depth of 6 feet in the Spring of 1987 to determine nutrient concentrations below the root zone, since earlier samples indicated elevated concentrations in the top 4 feet. Soil samples were collected from the same fields each sampling period so that general comparisons of soil nutrients could be made annually and seasonally in response to nutrient management.

6.8.6.4 Surface-water quantity and quality

Surface-water quantity and quality data were collected at two continuous-record stations and at five partial-record stations (fig. 6-3 and table 6-7). Station 1 is located in a wooded/residential area while the other stations are located in agricultural areas. Four partial-record stations and one continuous-record gage (Station 3) were located in the Nutrient-Management Subbasin. Two of the partial-record stations (Station 2 and 3) were discontinued in 1984 because the data were very similar to the data collected at sites immediately downstream. Another partial-record station (Station 9) was located in the Nonnutrient-Management Subbasin. The second continuous-record gage (Station 5) was at the downstream border of the Small Watershed and downstream of both the Nutrient-Management and Nonnutrient-Management Subbasins.

At the continuous-record stations, stream stage was measured and recorded using a graphic-stage recorder and an ADR. At the partial-record stations streamflow was measured with a current meter at the time of sample collection.

Water-quality samples were collected during base flow and stormflow. Base-flow samples consisted of discharge into the stream from both ground water and subsurface flow. Base flow was sampled monthly at the seven stations by collecting a depth-integrated sample from the stream cross-section. Whenever

Table 6-7.--Small Watershed study area surface-water data-collection stations

[mi^2, square mile; °, degree; ', minute; ", second; --, not applicable]

RCWP report station identification number	U.S. Geological Survey identification number	Station name	Station type	Drainage area (mi^2)	Latitude	Longitude
1	015760831	Little Conestoga Creek, Site 1, near Morgantown, Pa.	Partial record	0.34	40°09'22"	75°55'14"
--	015760832	Little Conestoga Creek, Site 2, near Morgantown, Pa. (Discontinued October 1984)	Partial record	.60	40°09'06"	75°55'05"
2	0157608325	Little Conestoga Creek, Site 2A, near Morgantown, Pa.	Partial record	.99	40°08'58"	75°55'06"
--	015760833	Little Conestoga Creek, Site 3, near Morgantown, Pa. (Discontinued October 1984)	Partial record	1.34	40°08'50"	75°55'24"
3	0157608335	Little Conestoga Creek, Site 3A, near Morgantown, Pa. (Nutrient-Management Subbasin)	Continuous record	1.42	40°08'47"	75°55'37"
4	01576089	Unnamed tributary to Little Conestoga Creek, Site 9, at Churchtown, Pa. (Nonnutrient-Management Subbasin)	Partial record	1.43	40°08'20"	75°58'14"
5	01576085	Little Conestoga Creek, near Churchtown, Pa. (Small Watershed study area)	Continuous record	5.82	40°08'41"	75°59'20"

possible, an attempt was made to eliminate the effect of storm flow on base flow; samples of base flow were collected a minimum of three days after the stream stage returned to near pre-storm base-flow levels. Samples of base flow from each site were analyzed for nutrients and suspended sediment, and at Stations 1, 3, and 5, for pesticides during the growing season. Samples of storm flow reflecting the discharge of the entire Small Watershed and the Nutrient-Management Subbasin were collected at Stations 5 and 3, respectively. Samples of storm flow were collected by automatic-pumping samplers when the stream stage exceeded a pre-set stage. The automatic-pumping sampler at Station 5 was equipped with a refrigeration unit. Because of the lack of accessible electric power, the automatic-pumping sampler at Station 3 did not have a refrigeration unit. Samples of storm flow at both sites were removed from the samplers and packed in ice immediately after storms. Selected stormflow samples were chemically preserved, chilled, and shipped to respective laboratories. Samples of stormflow were analyzed for suspended-sediment and nutrient concentrations, and several samples of storm flow were analyzed for pesticides. However, fewer samples were routinely analyzed for pesticides after it was discovered that pesticide containers had been disposed of in the wooded area in the most upstream portion of the Small Watershed near Station 1.

During the study, miscellaneous surface-water data were collected from periodic discharges of barnyard waste and tile lines. These data were collected to estimate the impact of periodic discharges on the quality of base flow. The effects of these discharges on stormflow were not determined because of the dilution of individual barnyard discharges and because outlets to the tile drains were submerged during stormflow.

6.8.6.5 Ground-water quality

To characterize ground-water quality, ground water was sampled three times per year at a network of six wells and two springs in the Nutrient-Management Subbasin (fig. 6-3). Three wells and one spring were located in carbonate rocks and the remaining three wells and one spring were located in noncarbonate rocks (table 6-8). These domestic wells and springs represent local conditions, and may not show the effects of BMPs, but did show a difference in ground-water quality between carbonate and noncarbonate geology. Sampling of this ground-water network was discontinued in November of 1987.

Table 6-8.--Small Watershed study area ground-water network stations

[°, degree; ', minute; ", second]

U.S. Geological Survey local identification number	Latitude	Longitude	Geologic formation
LNSP59	40°09'03"	75°55'15"	Buffalo Springs[1]
LNSP60	40°09'26"	75°54'45"	Stockton[2]
LN1586	40°08'53"	75°55'21"	Buffalo Springs
LN1662	40°09'10"	75°55'44"	Stockton
LN1663	40°08'43"	75°55'27"	Buffalo Springs
LN1665	40°09'22"	75°55'11"	Stockton
LN1666	40°09'26"	75°54'36"	Stockton
LN1678	40°09'18"	75°54'39"	Buffalo Springs

[1] Buffalo Springs Formation - light gray to pinkish gray, finely to coarsely crystalline limestone and interbedded dolomite; numerous siliceous and clayey laminae; stromatolitic limestone beds near top; some thin sandy beds (Berg, 1980).

[2] Stockton Formation - light gray to buff, coarse grained, arkosic sandstone, includes reddish brown to grayish-purple sandstone, mudstone, and shale (Berg, 1980).

6.8.6.6 Benthic macroinvertebrates

The benthic macroinvertebrates survey for the Small Watershed was part of the Regional survey. See section 6.7.6.6 for details.

6.8.7 Data Analysis

6.8.7.1 Precipitation

Precipitation data were compared with long-term records (1950-80) from the National Oceanic and Atmospheric Administration (NOAA) gage at Morgantown, Pennsylvania. Data from the precipitation gages at Field-Site 1 at Churchtown, Field-Site 2, at Ephrata, and the NOAA precipitation gage at Morgantown were used to estimate missing record for the gage at the Small Watershed. The NOAA gage and the gage at Field-Site 1 were within 4 mi (miles) of the study area, and the gage at Field-Site 2 was within 12 mi of the study area (fig. 6-1).

Precipitation data were tabulated to determine seasonal accumulations and determine annual differences. Data were plotted to show differences between monthly precipitation at the Small watershed and long-term normals at the NOAA station in Morgantown.

Precipitation data were also used to show relationships between precipitation, streamflow, and nutrient concentrations in base flow.

6.8.7.2 Agricultural activities

Annual summaries of crop acreage, crop yields, animal population and density, manure export, and applications of manure, commercial fertilizer, and pesticides were tabulated for the Nutrient-Management Subbasin.

Tabulations of animal populations and manure generated by the livestock were used to verify the agricultural-activity data. Monthly applications of nutrients from manure and commercial fertilizer were plotted to determine seasonal variations and trends prior to and during nutrient management. These plots were also used to show relationships between agricultural activities and the quality of base flow and stormflow.

Maps showing the proximity of agricultural activities such as animal density and grazing, nitrogen and phosphorus application rates, and tile-drain discharges to the stream were generated as an aide to determine the relationship of land use to water quality.

6.8.7.3 Soils

Soil data were plotted to determine depths in the soil and areas in the Nutrient-Management Subbasin where nutrients were concentrated, and thus, where the implementation of BMPs would be of most benefit. At first, it was hoped that an estimate of the amount of soluble nutrients stored in the soils could be determined; however, because of the high variability in the concentrations of soil nutrients between depths, fields, and time of sampling, and the continuous conversion of organic nutrients to highly soluble inorganic forms, it was determined that intensive monitoring of the soils, although critical, was beyond the original scope of the project. Thus, analysis of soil data was limited to general, descriptive summaries rather than quantifying, cause-and-effect relationships between nutrient applications and concentrations of nutrients in the soil.

6.8.7.4 Surface-water quantity and quality

Daily mean discharge records from the two continuous-record stations (RCWP Stations 3 and 5) and from the long-term continuous-record station at Conestoga River at Lancaster (1929-89), along with weather records, were compared to characterize the streamflow during the period of study. Correlations were determined between daily mean discharges at RCWP Stations 3 and 5 and Conestoga River at Lancaster.

Seasonal Kendall-trend tests were performed to determine trends in monthly mean discharges in the Small Watershed during the study, and the relationship of short-term trends at RCWP Stations 3 and 5 to long-term trends at the Conestoga River at Lancaster.

Streamflow hydrographs of the two continuous-record stations were separated to determine contributions to streamflow made by ground water (base flow) and surface runoff (stormflow). Hydrographs were separated using the local minimum method described by Pettyjohn and Henning (1979) and modified for computer use.

Daily, monthly, and annual loads of nutrients and suspended-sediment were calculated for RCWP Stations 3 and 5. Daily loads for days on which no stormflow occurred were computed by the following equation:

$$L = kCQ \tag{1}$$

where L = load, in pounds per day;
k = 5.4, unit conversion factor;
C = daily mean concentration, in milligrams per liter; and
Q = daily mean water discharge, in cubic feet per second.

Daily mean concentrations were estimated using straight-line interpolation between days on which base-flow samples had been collected. Daily loads for days on which stormflow occurred were computed from instantaneous sample results and measured discharge. Loads were estimated for unsampled storm days using regression equations derived from measured nutrient and suspended-sediment loads and measured discharge. Regression statistics were calculated separately for storms from the pre-BMP period and storms during the post-BMP period for both stations. Annual loads were calculated as the sum of the daily loads.

Base-flow data were analyzed using the paired-subbasins approach and the seasonal Rank-Sum trend test. The paired-subbasins approach was used to minimize the influence that climatic factors might have on trends in the data collected during the pre-BMP and post-BMP periods.

6.8.7.5 Ground-water quality

Summary tables were compiled of ground-water data and miscellaneous data from periodic discharges. The tables were used to identify general characteristics of ground water in the Small Watershed.

6.8.7.6 Benthic macroinvertebrates

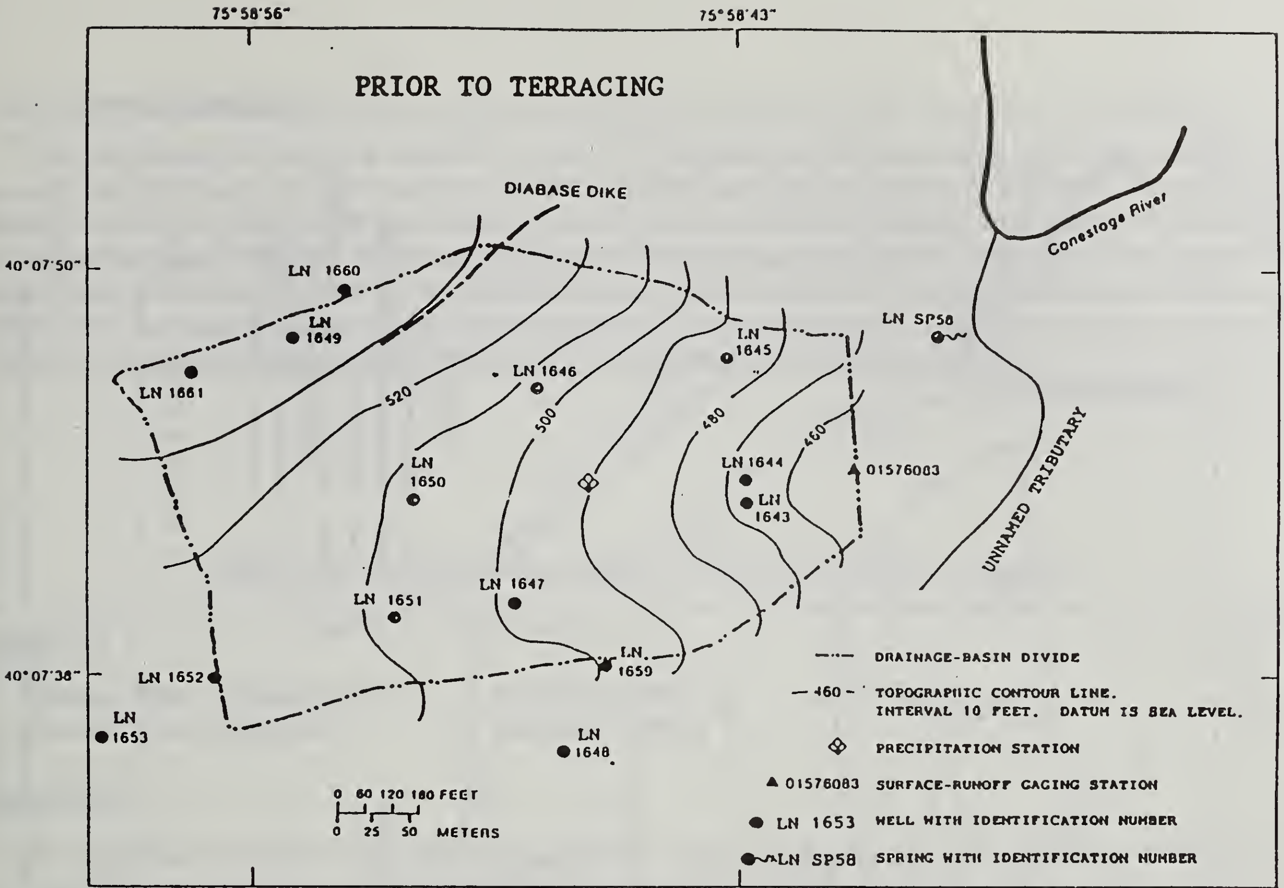
A benthic-macroinvertebrate survey was conducted using the procedures in PaDER's "Standardized Biological Field Collection Methods" (1988). Samples were collected in October 1988 and May 1989 at Stations 1, 3, and 4 in the Small Watershed study area. Water-quality samples were collected at the time of sampling for benthic macroinvertebrates.

6.9 FIELD-SITE 1

6.9.1 Location and Description

Field-Site 1 consists of 23.1 acres on two dairy farms, and is shown in figures 6-5 and 6-6. The site is located in the Conestoga River headwaters, between Churchtown and Goodville in northeastern Lancaster County, Pennsylvania.

The ground-water basin, shown in figure 6-6, is slightly larger than the 23.1 acre field site. The boundaries of the ground-water system were estimated using water-level, geologic, and physiographic data. All discharge from the ground-water system occurs along the eastern boundary of the field site.



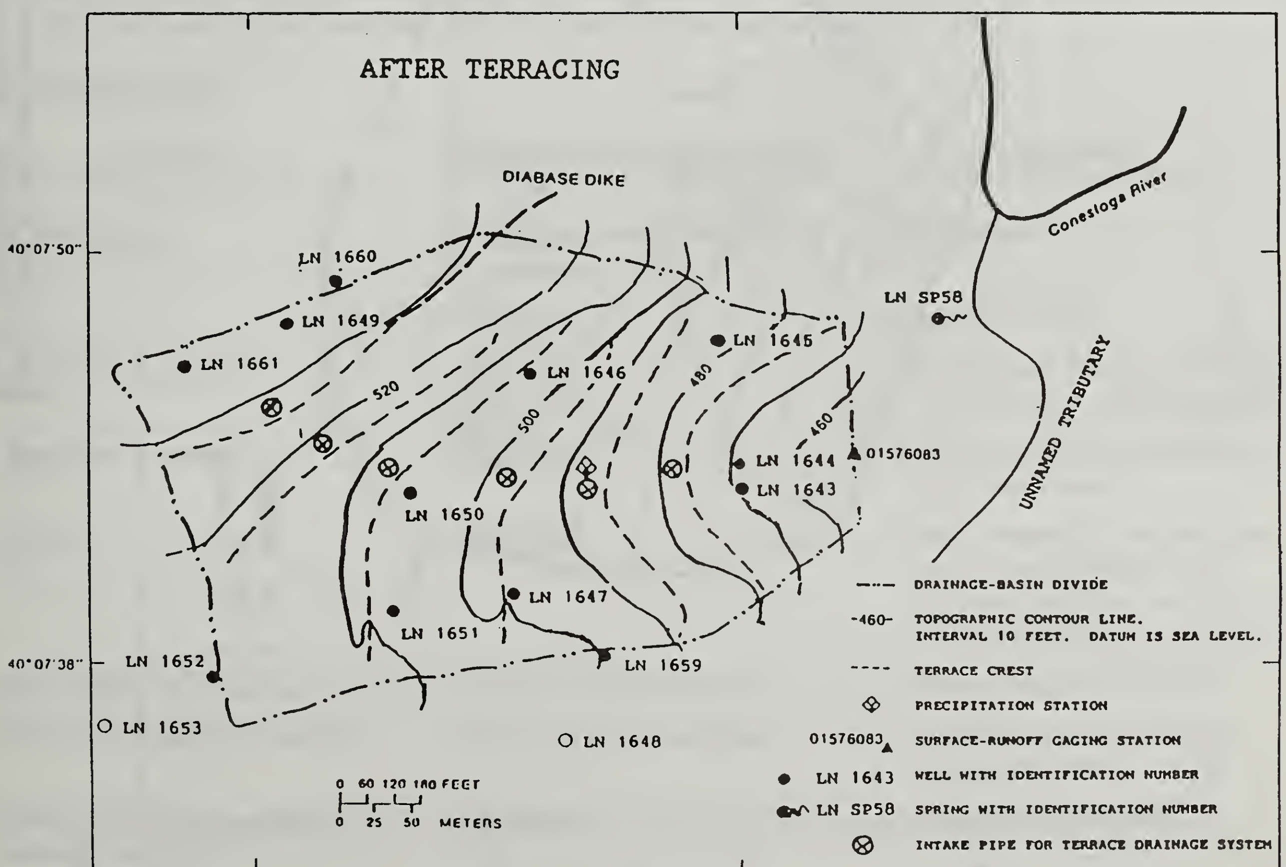


Figure 6-5.--Field-Site 1 surface-runoff, ground-water, and precipitaion station locations prior to and during implementation of terraces and nutrient management.

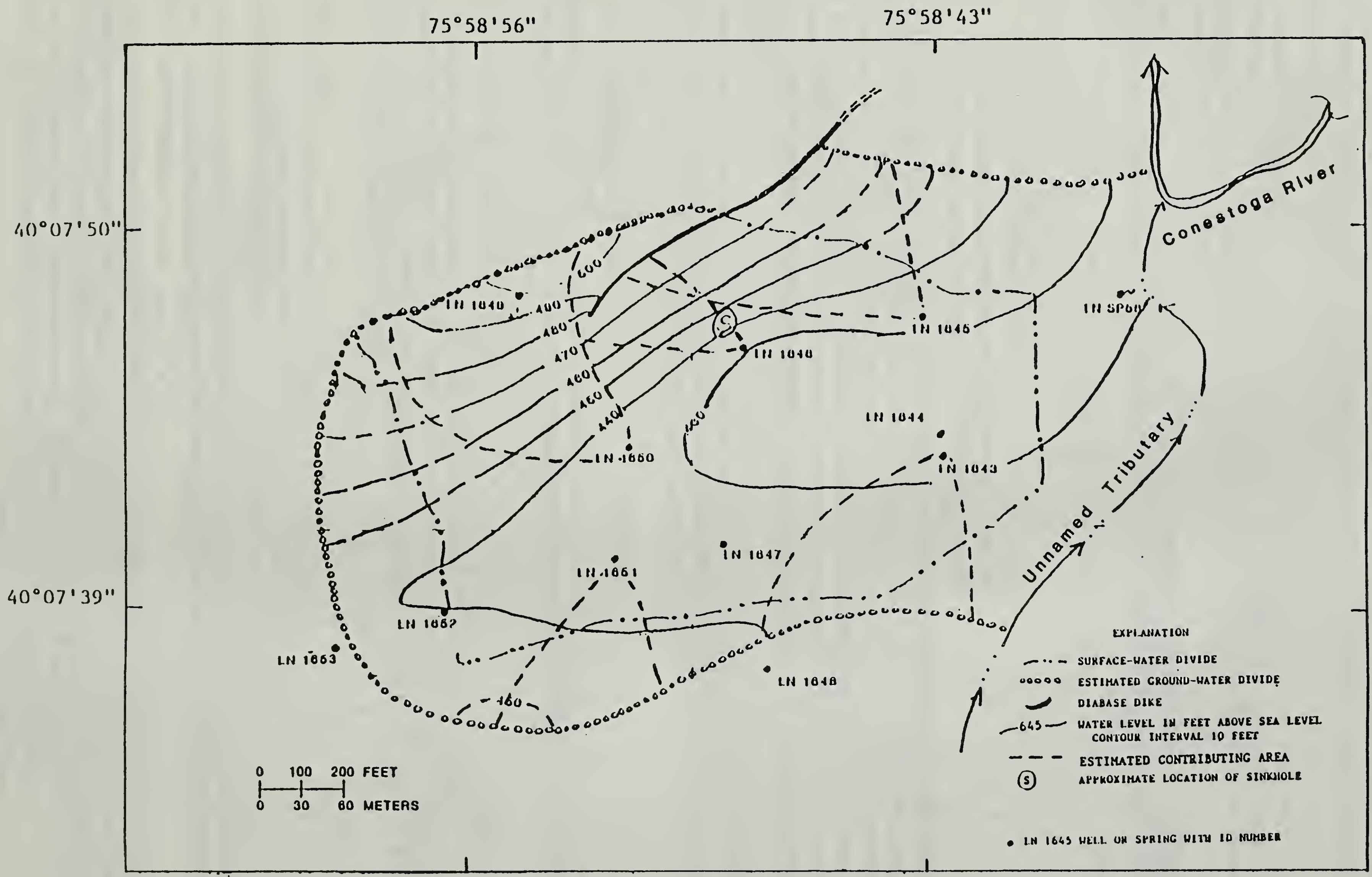


Figure 6-6.--Field Site 1 surface-water and ground-water basins, and estimated areas contributing recharge to ground-water stations.

6.9.2 General Strategy

The monitoring strategy is shown on table 6-9. Ground water was monitored from October 1982 through July 1989 and surface runoff was monitored from January 1983 through July 1989. The monitoring strategy was developed to compare data collected prior to (pre-BMP), during, and following (post-BMP) the implementation of BMPs. The farmers followed their normal agricultural activities during the pre-BMP period, and then implemented the recommendations in their respective conservation plans developed by USDA-SCS. Recommendations included the construction of terraces and a manure storage facility, and nutrient-management plans developed by the Penn State Cooperative Extension.

Table 6-9.--Monitoring strategy for the Field Site 1 study area

SCHEDULE

October 1982 - September 1984	Pre-BMP period
October 1984 - July 1989	post-BMP period

APPROACH

To determine the effects of nutrient management, animal-waste storage, and terraces, pre-BMP and post-BMP concentrations and discharges of suspended sediment, nutrients, and pesticides, and water levels were compared. Land-use data were used in interpretation of the data.

DATA COLLECTION

Location	Constituent or parameter	Frequency
1 Runoff gage	Suspended sediment and nutrients	Major storms
	Pesticides	Selected storms
5 Wells and 1 spring	Nutrients	Monthly and during an average of 3 recharge events per year
3 Wells and 1 spring	Pesticides	Selected months/discontinued 1985 water year
2 Wells	Pesticides	Selected months, concentrating around application and growing periods, and during a few selected recharge events
Soil (number of locations varied)	Nutrients and pesticides	Spring, summer and fall
17 Soil-water sample locations	Nutrients and pesticides	Periodically/discontinued September 1984
Manure from barn, wagon, or storage facility	Nutrients	At time of application
1 Precipitation station	Precipitation intensity and total accumulation	5-minute intervals
	Nutrients	Periodically
2 Farms	Agricultural-activity data	Biweekly

6.9.3 Land Use

The field site consisted entirely of cropland. During the pre-BMP period the site encompassed 22.1 acres. Surface-water drainage changes made during the construction of the pipe-outlet terraces resulted in a slight increase in the surface-water drainage area to 23.1 acres. Approximately 85 percent of the field site, the section located close to the surface-water gage, was owned by one farmer and the remaining 15 percent was owned by the second farmer.

Both farms were typical of dairy farms in the Conestoga Headwaters RCWP Project Area. The farm with the greater percentage of land in the study area is an 80-acre farm with an average annual animal population of 65 dairy cows and 30 heifers, equivalent to 115 animal units (one animal unit is equal to 1,000 pounds of animal weight). The remaining portion of the field site was part of a similar dairy farm with an average annual animal population of 56 dairy cows and 10 heifers, equivalent to 71 animal units.

Conventional moldboard plow tillage was practiced at the field site. Each Spring of 1983-85 when the field was plowed, soil was pushed into a long deep gully that had formed west to east in the center of the lower corn field and continued to the gaging station. Other smaller gullies branched from the larger one. Beginning with the first heavy rains after plowing, soil washed from the gullies into the receiving stream. By the end of the summer during the pre-BMP period, the gully deepened to 3 ft deep and widened to 2 ft wide, and exposed large boulders lining the gully. For the 1986-89 crop years, this field was planted in alfalfa.

Fields were spread unevenly with manure and commercial fertilizer in late April and May. The largest applications were made to cornfields. The field in the southeast corner, near the barn, received most of the manure during the pre-BMP period. Herbicides were also applied to the fields planted in corn.

Corn and alfalfa were the predominate crops raised at the site. Other crops include soybeans, tobacco, rye, pumpkins, and cole crops. Generally, the site was plowed with a moldboard plow and disked in April, corn planted in May, and then corn was harvested as silage in September. Some years, rye was planted as a cover crop after the corn was harvested. Rye was turned under with the spring plowing. Alfalfa was cut three to four times a year. Alfalfa fields remained undisturbed throughout the winter.

Two BMPs were implemented at the site during the 1985 water year. Pipe-outlet terraces were constructed in the fall of 1984, and reconstructed after storm damage in May 1985. The terraces were designed to contain runoff from a 5-inch, 24-hour storm and then release that water during the course of a 24-hour period. As part of the terracing plan, the cropping pattern was changed in 1985 so that alfalfa was grown on the steepest, lower section of the field site.In addition, a 225,000 gallon concrete manure-storage facility was constructed and made operational in November 1984 to provide 6 months of storage capacity. This caused the timing of nutrient applications to change. Nutrient management was implemented at both farms during the 1985 growing season, but did not have a large impact on nutrient application quantities.

6.9.4 Geology

The field site lies within the Piedmont physiographic province in the Conestoga Valley section (U.S. Department of Agriculture, 1985). The Conestoga Valley section consists predominantly of carbonate, sedimentary, and metasedimentary rocks that have been deformed repeatedly by folding and faulting.

The site is underlain by dolomitic rocks of the Cambrian-aged Zooks Corner Formation. The Zooks Corner Formation consists primarily of interbedded, thin- to thick-bedded, white to medium-dark gray, finely crystalline dolomite, silty and sandy dolomite, and dolomitic sandstone (Meisler and Becher, 1971). Lithologic logs developed during the drilling of 14 wells indicate that above the relatively fresh Zooks Corner dolomite is a 10- to 100-ft-thick weathered zone which extends upward to the soils. Numerous cavities and voids, in some areas filled with silt and clay, are present at all depths within both the weathered and fresh dolomite.

Although no outcrops of the Zooks Corner Formation were found at the site, nearby outcrops of the Ledger Formation were used for field measurements of strike and dip of the Zooks Corner Formation. The Ledger Formation conformably overlies the Zooks Corner Formation and has a similar geologic history. Jointing of the rock in this area has a preferential NE to SW trend. Strike measurements of the formation

ranged from about N. 60° E. to N. 70° E., and dip measurements ranged from about 40° NW. to 70° NW. Mean values for strike and dip are N. 65° E. and 54° NW., respectively.

A diabase dike of Triassic age extends approximately 300 feet at an east-northeast trend into the north-central part of the study area (fig. 6-5) (Berg, 1980). A ground-magnetic geophysical survey verified the position and the areal extent of the dike. This impermeable dike impedes the flow of ground water and contributes to an elevated water table in the northwestern part of the study area.

Unsaturated materials are 5- to 70-feet thick, as determined by well drilling logs, and are highly permeable. Secondary porosity in the soils and regolith of the unsaturated zone facilitates rapid movement of water and dissolved materials from the land surface to the water table. As is typical in karstic carbonate areas, solutionally-developed passages along bedding planes, fractures, joints, and cleavage are the dominant pathways for groundwater flow.

6.9.5 Soils

Soils at Field-Site 1 are classified as Duffield silt loam and Hagerstown silty clay loam (U.S. Department of Agriculture 1985). These well drained soils form in residuum of weathered carbonate rock. Generally, clay content in the upper 6 in. ranges from 13 to 25 percent. Hagerstown soils, however, generally contain up to 45 percent clay at depths of 20 to 50 in. below land surface compared to 20 percent clay in the same depth interval of Duffield soils. Soil pH is acidic, from 6 to 7 units at the surface and 5 to 6 units in subsoils. Cation-exchange capacity of the soils ranges from 10 to 20 mg per 100 grams, with the highest capacities near the surface (U.S. Department of Agriculture, 1985). Slopes ranged from 2 to 22 percent with a median slope of 6 percent.

6.9.6 Data Collection

6.9.6.1 Precipitation

Precipitation quantity and intensity data were collected in the Field-Site 1 study area. The precipitation gage recorded accumulated precipitation at 5-minute intervals using a rain gage equipped with an analog-digital recorder (ADR) sensitive to precipitation amounts as little as 0.014 in. The precipitation gage was operational from December 1982 through July 1989. Precipitation data were processed and stored in a computer data file at the USGS office in Lemoyne, Pennsylvania, so that data analysis could be performed. Data collected at the field site was compared with long term data collected at the National Oceanic and Atmospheric Administration precipitation station at Morgantown, Pennsylvania, and compared to the record for the corresponding time period to estimate missing record.

Precipitation-quality samples were collected twice a year during the study. Samples were collected using a 13-inch glass funnel which collected precipitation into a glass jar that was packed in ice to keep the sample chilled to 4 °C. Precipitation samples were analyzed for dissolved nitrogen species and phosphorus by the PaDER laboratory in Harrisburg, Pennsylvania.

6.9.6.2 Agricultural activities

The USGS generally collected agricultural-activity data biweekly from farmers at Field-Site 1. Agricultural activity data included timing, location, and amount of commercial-fertilizer, manure, and herbicide applications, and plowing, planting, and harvesting information.

6.9.6.3 Soils

Soil samples were collected from Field-Site 1 by the Pennsylvania State University, College of Agronomy, and analyzed for soluble nitrate nitrogen and soluble phosphorus by the University's Soils and Environmental Chemistry Laboratory. Samples from the plow layer were collected by the Penn State Cooperative Extension and analyzed for Bray-1 phosphorus by the University's Merkle Laboratory. Concentrations of pesticides in soil samples were determined by laboratories contracted by the USGS laboratory in Arvada, Colorado.

Four types of soil samples were collected from various depths and locations at Field-Site 1. Soil sampling changed as a result of technology developed during the monitoring period.

The first type of soil samples were samples of the top 2 in. of soil composited from 13 locations into a 1-quart glass bottle. Composite soil samples were analyzed for particle-size distribution, pH, major ions, nutrients, and triazine herbicides. The second type of soil samples, 2-ft soil cores, was collected in the fall of 1983 after harvest at 13 locations (D. Baker, Pennsylvania State University, written commun., 1984). Each 2-ft core was split into two 1-ft sections and analyzed for soluble nitrate. The third type of sample was collected in April 1984. The top 8 in. of soil (plow depth) was sampled at three locations: the upper cornfield just west of the alfalfa, the center of the alfalfa field, and the lower cornfield just east of the alfalfa. In addition, samples from the plow layer were collected by Penn State Cooperative Extension and analyzed for Bray-1 phosphorus by the University's Merkle Laboratory. The fourth type of samples were a 4-ft core sample collected in the spring and fall using a deep-soil probe, beginning in the fall of 1984 by the Pennsylvania State University, College of Agronomy, split into increments of 0-8, 8-24, and 24-48 inches, and were analyzed for soluble nitrate nitrogen and soluble phosphorus by the University's Soils and Environmental Chemistry Laboratory.

6.9.6.4 Surface-runoff quantity and quality

Surface runoff from the field, both before and after terracing, was routed through a 9-in. Parshall flume located beside the gage (USGS number 01576083) house at the base of the field. The water level in the flume was measured with a graphic-stage recorder and an ADR. Runoff samples were collected with a float/stage-triggered PS-69 automatic-pumping sampler that was modified with a refrigeration unit to keep samples chilled. Perforated intakes for the automatic sampler were positioned in the center of the flume. The time of sample collection was recorded using an event marker that was triggered to mark the graphic record when the sampling pump was engaged.

6.9.6.5 Ground-water quantity and quality

Ground water was monitored at 14 wells and one spring at Field-Site 1 (fig. 6-5 through 6-7, and table 6-10). Fourteen wells were drilled specifically for this project. The wells were drilled using air-rotary methods, cased to solid bedrock, then continued as open holes to the first major water-bearing zone in the unconfined, carbonate-rock aquifer. The 6-in. steel well casings were grouted in place and bentonite was used as an additional surface seal. Seven of the wells were equipped with continuous water-level recorders. Recorders at two wells, LN 1649 and LN 1659, were not operational for the entire seven-year monitoring period. Water-quality monitoring was conducted at five of the wells and at the spring through the study period. Samples from the wells were collected using a point sampler adjacent to major water-bearing zones, which ranged from 62 to 112 feet below land surface. The wells were not pumped prior to sampling because preliminary analysis showed that statistical differences in chemical concentrations could not be detected between samples collected after pumping and samples collected prior to pumping when the samples were collected adjacent to the major water-bearing zone at each well (Lietman and others, 1989). Ground water was sampled and analyzed for specific conductance and concentrations of nutrients every 3 to 4 weeks during nonrecharge periods, more frequently during selected recharge periods, and for herbicides periodically throughout the study. Several times between October 1982 and September 1983, ground-water samples were analyzed for major ions, and water temperature was measured.

Seventeen lysimeters were installed to collect samples of the water in the unsaturated zone. However, most of the lysimeters proved to be ineffective, primarily because of the clay-rich soils at Field-Site 1. Also, they were destroyed during plowing in October 1984.

Table 6-10.--Field-Site 1 study area ground-water data-collection locations and descriptions

[All depths shown in feet below land surface; [(gal/min)/ft], gallon per minute per foot; <, less than; E, estimated value; °, degree; ', minute; ", second; NA, not applicable; --, no data;]

Well number	Latitude (°, ', ")	Longitude (°, ', ")	Total depth of well	Depth of bottom of casing (overburden thickness)	Depth to bedrock	Depth to water table surface: Maximum (lowest water level)	Depth to water table surface: Minimum (highest water level)	Specific capacity [(gal/min)/ft]	Data collected[1]	Sampling depth
LN SP58	40 07 44	75 58 39	Spring	NA	NA	NA	NA	NA	N + I	NA
LN 1643	40 07 41	75 58 43	100	68.9	20	38.75	33.66	20	NWL + I	82
LN 1644	40 07 42	75 58 43	75	77.6	22	--	--	30	WL	43
LN 1645	40 07 46	75 58 43	80	24.2	7	52.53	49.00	160	NWLP + I	62
LN 1646	40 07 44	75 58 47	125	99.4	5	73.21	69.47	130	NWLP + I	107
LN 1647	40 07 40	75 58 49	75	37.3	17	--	--	<.25	WL + I	65
LN 1648	40 07 38	75 58 46	100	7.2	2	--	--	.50	WL + I	72
LN 1649	40 07 44	75 58 54	85	38.7	35	37.94	29.35	14	NWL + I	72
LN 1650	40 07 41	75 58 51	125	89.7	63	74.52	70.14	36	NWL + I	112
LN 1651	40 07 39	75 58 51	105	71.7	68	71.27	62.65	20	NWL + I	92
LN 1652	40 07 38	75 58 53	125	79.5	12	--	--	<.25	WL + I	83
LN 1653	40 07 37	75 58 56	132	105.1	27	--	--	3.0	WL + I	117
LN 1659	40 07 39	75 58 45	142	E84	18	--	--	.50	WL	98
LN 1660	40 07 45	75 58 53	150	39.2	12	--	--	.75	WL	73
LN 1661	40 07 44	75 58 56	75	38.5	20	--	--	3.0	WL	63

[1] NWLP, Nutrient, continuous water-level, and herbicide data; NWL, Nutrient and continuous water-level data; WL, Intermittant water-level data only; N, Nutrient data only; + I, sampled for major ions.

6.9.7 Data Analysis

6.9.7.1 Soils

Summary statistics were calculated to determine locations where nutrients and herbicides were concentrated in the soils. Soil data were also investigated to determine seasonal variations in concentrations of herbicides and to determine general degradation characteristics of applied herbicides.

6.9.7.2 Surface runoff

Flow-weighted mean-storm concentrations and loads were calculated from continuous graphs of discharge and constituent concentrations constructed using recorded stage and laboratory data from the discrete storm samples analyses using methods described by Porterfield (1972).

Runoff and associated precipitation and agricultural-activity data were grouped by several methods. The entire pre-BMP period, from January 1983 through September 1984 is referred to as Period 1. Data from the post-BMP portion of the study is grouped together and broken down into three time periods: Period 2 [1985 and 1986 water years (October 1, 1984, through September 30, 1985, is the 1985 water year)], Period 3 (1987 and 1988 water years), and Period 4 (the 1989 water year).

Suspended-sediment and nutrient loads for unsampled runoff events were estimated using regression equations for periods derived from log-transformed suspended-sediment and nutrient loads versus log-transformed total runoff for sampled runoff events. The regressions were performed separately for data from the growing season (May through October) and the nongrowing season (November through April). Scatter plots were used to verify the significance of the regression analyses. Data for estimated and sampled individual runoff events were summed to estimate the monthly and annual loads.

Various statistical procedures, were used to compare runoff data collected prior to and during the implementation of the BMPs.

Regression analysis of suspended-sediment and nutrient loads and associated total storm discharges were used to compare periods. Analysis of covariance was used to determine statistically significant differences between periods for constituent loads as a function of discharge.

The Mann-Whitney nonparametric test was used to test differences in percent runoff and mean storm suspended-sediment and nutrient concentration between periods.

The runoff data was further grouped using cluster analyses based on four precipitation characteristics and a ranked value for crop cover. Within the clusters, the pre- and post-BMP data were compared using the Mann-Whitney procedure. To determine statistically significant differences, pre-BMP data for total discharge, and suspended-sediment and nutrient concentration and loads were compared to data for entire post-BMP period and to data for Period 2and Period 3.

6.9.7.3 Ground water

Specific yield, specific capacity and transmissivity were calculated to characterize ground-water conditions at the site. Specific yield of the aquifer was estimated based on water-level rise measured at well LN 1643 during recharge periods that were defined as periods with high soil moisture and negligible evapotranspiration (Gerhart, 1986; D.W. Hall, U.S. Geological Survey, written commun. 1990). Water-level data from well LN 1643 were used to calculate the specific yield because little data were missing from the record of this well during the study, and because the range and shape of the water-level hydrograph from well LN 1643 were most similar to the range and shapes of hydrographs from other wells. Rises in water-level that resulted from rain on frozen ground, rain on snow, or snowstorms, were not used because less infiltration and time lags in the response by water level occurred from these events. Specific yield was calculated according to the equation:

$$\text{Specific yield} = (P-R)/WLR \tag{2}$$

where P = precipitation, in inches;
R = runoff, in inches; and
WLR = water-level rise in well, in inches.

Changes in water level were used to classify samples as either recharge or nonrecharge samples. Nonrecharge samples were used in most of the data analysis. Samples collected within a week of a 0.3 foot or greater rise in water level were classified as recharge samples. All other samples were classified as nonrecharge samples. If more than one nonrecharge sample was collected within a month, the sample collected closest to the 15th of the month was used in the data analysis. If more than one recharge sample was collected during a month containing no nonrecharge samples, the recharge sample collected closest to the fifteenth of the month was used. If no nonrecharge sample was collected during a month, a recharge sample was used in the data analysis. The decision to use recharge samples, if necessary, was based on boxplots which showed no difference between the distribution of recharge and nonrecharge samples, although temporary increases or decreases in concentrations of nitrate were measured in recharge samples for up to one week after a precipitation event.

Specific capacities of the wells were calculated using estimates made by the driller and pump tests conducted on the wells shortly after well completion.

Transmissivity was calculated from estimates of specific capacity using methods described by Driscoll (1986). The following equation was modified from the Jacob equation to calculate transmissivity:

$$Q/s = T/[264(\log 0.3Tt)/r^2 s]\ , \tag{3}$$

where Q = yield of well, in gallons per minute,
s = drawdown of well, in feet,
T = transmissivity, in feet squared per day,
t = time of pumping, in days,
r = radius of well, in feet, and
S = storage coefficient of the aquifer.

The values used for t and Q were determined from the pump tests, r was equal to 0.25 feet, and S was assumed to be equal to the specific yield.

Changes in proportional amounts of ground-water recharge occurring upgradient of six wells at the site were evaluated using double-mass plots of water-level data to determine the effects of terracing on rates of recharge. Changes in annual water levels in five wells were discussed in relation to terrace-induced changes in rates of recharge.

Ground-water discharge from the site was estimated using the assumption that annual recharge entering the site approximates annual discharge. Discharge from the site was prorated, by month, using water-level data and Darcy's Law to provide estimates of proportional monthly discharge. Darcy's Law (Freeze and Cherry, 1979) states:

$$D = (K)\,(A)\,\frac{\Delta h}{\Delta l}\ , \tag{4}$$

where D = Discharge, in cubic feet per minute;
K = Hydraulic conductivity, in feet per minute;
A = Cross-sectional area, in square feet; and
$\frac{\Delta h}{\Delta l}$ = Hydraulic gradient, dimensionless.

Relations of ground-water quality to land use, agricultural activities, and recharge at Field-Site 1 were investigated. Concentrations of nitrate in water samples from four nearby wells in nonagricultural areas were compared to concentrations in samples from wells at Field-Site 1 to estimate differences in ground-water quality caused by agricultural land use. The effect of surface-applied materials on ground-water quality at the site during the percolation of recharge was shown by plotting times of applications of herbicides to the surface and concentrations of herbicides in ground water.

Relationships between the surface spreading of manure and commercial fertilizer, concentrations of nitrate in soil water, and concentrations of nitrate in ground water were shown by plotting times of manure applications, concentrations of nitrate in soil water from lysimeters that were installed at depths of 3, 6, and 9 ft, and concentrations of nitrate from a nearby well.

Estimates of areas where nitrogen applications contribute nitrate to ground water were made by estimating lines of gravimetric flow paths upgradient of each well, which were expanded to account for hydrodynamic dispersion. Dispersion was assumed to occur vertically, as constituents infiltrate through the unsaturated zone, and horizontally as constituents move downgradient through the aquifer (Bouwer, 1978). Dispersion estimates were based on an arbitrarily selected 1:1 ratio of longitudinal flow distance to lateral dispersion, thus delineating a land area of maximum influence of surface-applied materials on ground-water quality.

The time of travel of infiltration and associated nitrate movement through macropores and micropores, and the effects of recharge on ground-water quality were studied by plotting the time of occurrence of precipitation, rises in the water table at wells, and changes in concentrations of nitrate in groundwater.

Nitrate concentrations in ground-water samples collected during the pre-BMP and post-BMP periods were tested for significant change using the Mann Whitney test.

6.9.7.4 Hydrologic and nitrogen budgets

A hydrologic budget was estimated for Field-Site 1 using the equation:

$$\text{precipitation} = \text{surface runoff} + \text{ground-water recharge} + \text{evapotranspiration.} \qquad (5)$$

Ground-water storage was assumed to be zero on an annual basis and was omitted from the equation. All of the variables in the equation were measured or estimated on a monthly basis, and monthly values were summed to obtain annual budgets.

A simplified nitrogen budget for Field-Site 1 was determined using measured and estimated values for inputs and outputs of nitrogen. Inputs of nitrogen included manure, commercial fertilizer, and precipitation. Outputs of nitrogen included discharge from the ground-water-flow system, discharges from surface runoff, nitrogen volatilized from manure, and nitrogen removed by crops.

Data from Field-Site 1 were also compared to results generated from a mathematical model. Crowder and Young (1985) modeled the nitrogen and phosphorus losses in the Conestoga River headwaters RCWP project area using the Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model and stated that results from the model should be used only to compare relative effects of BMPs on surface- and ground-water quality, and not to real data. However, realizing the limitations of the model, and because the model was used for evaluating the project area and its output is being used by agricultural planners to evaluate the retention of nitrogen, phosphorus, and sediment in the study area, a comparison of the model's output to real data was made to complete the objectives of this study.

6.10 FIELD-SITE 2

6.10.1 Location and Description

Field-Site 2, a 47.5-acre area of a 55-acre farm shown in figure 6-7, is part of a larger watershed located in the Conestoga River headwaters, near Ephrata in northeastern Lancaster County, Pennsylvania. Surface elevation at the site ranges from 342 feet in the southeastern corner to 430 feet at the southwestern corner, for a total relief of 88 feet. The slope of the land surface ranges from about 2 to 9 percent, with median slopes of about 5 percent.

The surface-water basin is defined by the terracing system of which 27 acres are drained by a pipe-outlet network, property boundaries, and Indian Run.

The ground-water basin extends beyond the northern, southern, and western site boundaries. Locations of the flow of ground water across these boundaries were estimated using topography, measured ground-water levels, and Modflow, a two-dimensional finite-difference model. Discharge from the ground-water system is to Indian Run and occurs along the northern, eastern, and southern boundaries of the study site.

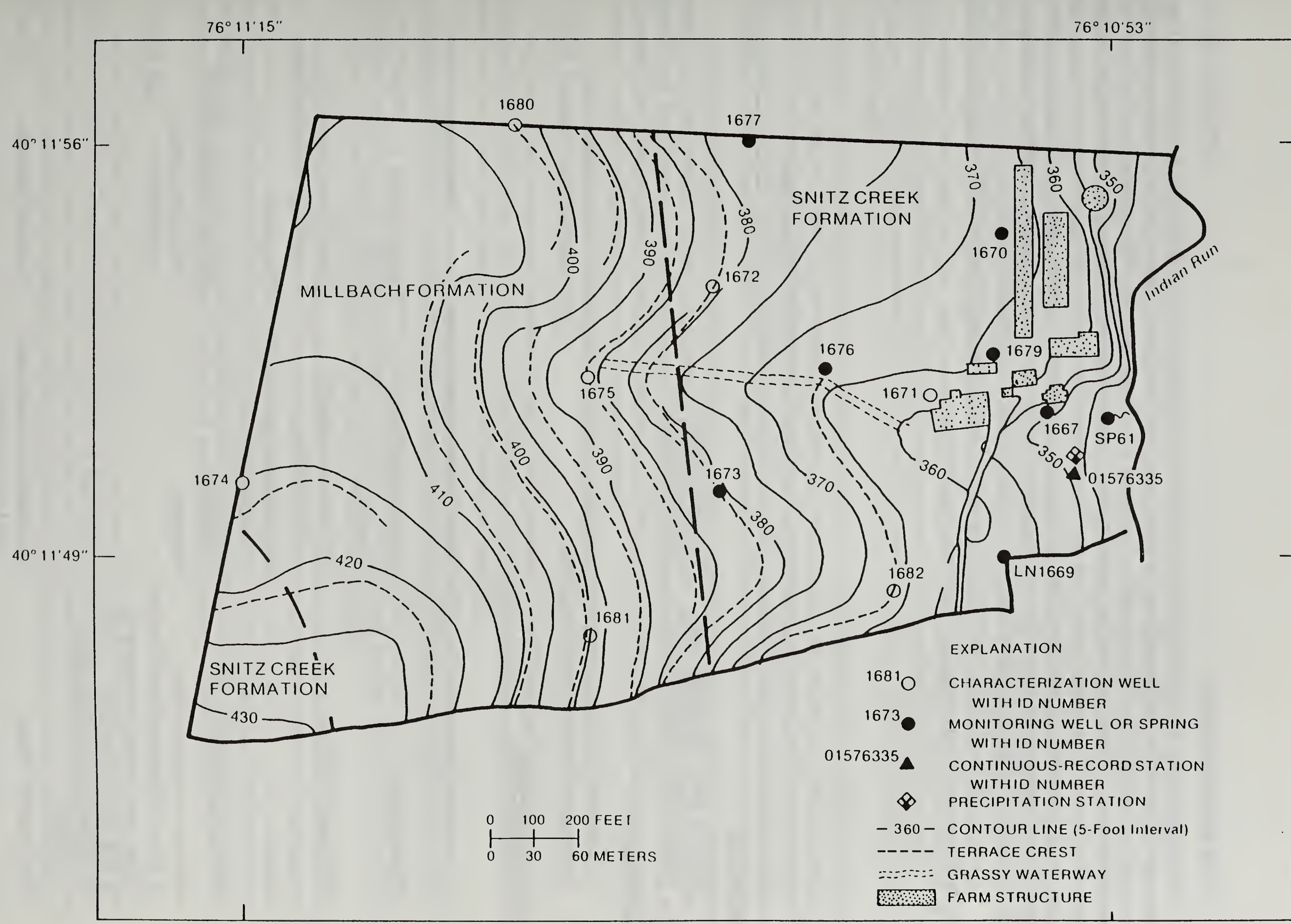


Figure 6-7.--Field Site 2 surface-runoff, ground-water, and precipitaion station locations.

6.10.2 General Strategy

The monitoring strategy is shown on table 6-11. Surface water was monitored from October 1984 through October 1988, and ground water was monitored from October 1984 through September 1990. The monitoring strategy was developed to compare data collected prior to (pre-BMP) and after the implementation of the nutrient-management BMP (post-BMP). The farmer followed his normal agricultural activities during the pre-BMP period, and then implemented the nutrient-management plan developed for him by Pennsylvania State University, College of Agriculture Extension Service. Recommendations included adjusting the timing and amounts of applications of manure and commercial fertilizer as indicated in a nutrient-management plan developed by the Penn State Cooperative Extension.

Ground-water monitoring of Field-Site 2 is being continued through 1993 by USGS in cooperation with PaDER as part of Pennsylvania's Chesapeake Bay Program.

Table 6-11.--Monitoring strategy for the Field Site 2 study area

SCHEDULE

October 1984 - September 1986	Pre-BMP period
October 1986 - September 1990	Post-BMP period

APPROACH

To determine the effects of nutrient management, pre-BMP and post-BMP concentrations and discharges of nutrients were compared.

DATA COLLECTION

Location	Constituent or parameter	Frequency
1 Runoff gage	Suspended sediment	Major storms
	Nutrients	Selected storms
4 Wells and 1 spring	Nutrients and specific conductance	Monthly and during 3 recharge events per year
2 Wells	Nutrients and specific conductance	Quarterly
3 - 17 Soil-sample locations	Nutrients	Spring, summer, and fall
4 Manure-storage locations 1. manure/bedding from steer pen 2. hog manure from storage tank 3. hog manure from pit 4. chicken manure from poultry house	Nutrients	At time of selected applications
1 Precipitation station	Precipitation intensity and total accumulation	5-minute intervals
	Nutrients	Periodically
1 Farm	Agricultural-activity data	Monthly

6.10.3 Land Use

The field site consisted of the 47.5 cropped acres of the farm. Part of the site was terraced for control of soil erosion prior to the beginning of the study. The terraces were originally installed in 1965 and then were reconstructed and a pipe-outlet drainage system was installed on 27 acres in 1981. Runoff from the pipe-drained terraces is intercepted by 10 standpipes and discharged from a single pipe outlet to Indian Run (fig. 6-8).

The primary crops planted at the site were corn and tobacco. In addition sweet corn, cantaloupes, pumpkins, tomatoes, peppers, potatoes, and strawberries were grown in small quantities. The cropping patterns changed slightly from year to year, as tobacco acreage was rotated and fruits and vegetables were planted starting in 1988. Nutrient management was implemented at the site in October 1986.

Field-Site 2 is typical of other small farms that house steers, hogs, and/or poultry in the Conestoga Headwaters RCWP Project Area. The farm has an average annual animal population of 100 beef cattle, 1,500 hogs, and 110,000 chickens, equivalent to 2.9 animal units per acre (one animal unit is equal to 1,000 pounds of animal weight).

Minimum till and notill practices were used from 1985 until 1988. Minimum till consisted of chisel plowing in the fall and cultivating before spring planting. Notill included use of rye as a winter cover crop. The rye was sprayed with a herbicide in preparation for the planting of corn, and then corn was planted through the rye residue. In 1988, the tillage practice was changed to a modification of the slit-till method. This tillage practice, combined with no cover crop, was used for the remainder of the monitoring period.

Fields received nutrients from the spreading of manure, commercial fertilizer, and other agricultural waste. Application rates varied substantially between fields. Steer and poultry manure were surface-spread, and hog manure was both surface-spread and injected into the soil. When the soil was frozen, all manures were surface-spread. Commercial fertilizers were broadcast with pre-emergent herbicides prior to planting or applied as sidedress only in the growing season.

6.10.4 Geology and Hydrogeology

Field-Site 2 lies within the Piedmont physiographic province in the Conestoga Valley section (U.S. Department of Agriculture, 1985). The Conestoga Valley section consists predominantly of carbonate and shale rocks that have been deformed repeatedly by folding and faulting.

Approximately half of the site is underlain by limestone of the Millbach Formation, and the remainder is underlain by dolomite of the Snitz Creek Formation. The Millbach and Snitz Creek Formations are of the Cambrian age. The Millbach Formation is light-pinkish-gray to medium-dark-gray, finely-to very-finely-crystalline limestone with light-gray laminae of dolomite (Meisler and Becher, 1971). The Snitz Creek Formation is a light-to dark-gray, finely- to very-finely-crystalline dolomite.

Lithologic logs developed during the drilling of 13 wells indicate that the bedrock of limestone and dolomite ranges between 5 to 30 feet below land surface. Soils and weathered regolith in the unsaturated zone formed in the residuum of the carbonate bedrock. The bedrock surface and the water table nearly coincide with one another across much of the site. Where the bedrock is not sufficiently fractured to permit infiltration, water may pool and move downgradient along the bedrock surface. Where solution enlarged fractures, joints, and bedding planes have formed, water enters the bedrock.

6.10.5 Soils

Soils at Field-Site 2 are classified as slightly- to severely-eroded Hagerstown silt loams and silty-clay loams with reddish clay subsoils (U.S. Department of Agriculture 1985). Soils are typically deep and well-drained, and formed in residuum from weathered limestone. Unsaturated zone thickness to bedrock ranges from 5 to 30 ft. In some areas of the site, soils may be mixed with subsoils due to erosion, cultivation, and terracing.

Particle-size analysis of the top 2 in. indicated a clay content of 27 percent, and a silt content of 56 percent. Typically, clay content of topsoil ranges from 13 to 25 percent and increases to 50 percent at depths

of 20 in. From there, the clay content remains stable to a depth of 60 in., below which the clay content decreases (U.S. Department of Agriculture, 1985).

Soil pH is acidic at Field-Site 2; pH ranges from 4.5 to 6.5 with the maximum pH occurring in the upper 20 in. Below 20 in., pH decreases and approaches 4.5 at a depth of 80 in. The cation-exchange capacity of the soil ranges between 15 to 20 milliequivalents per 100 grams to a depth of 60 in. Below that depth the cation-exchange capacity decreases (U.S. Department of Agriculture, 1985).

6.10.6 Data Collection

6.10.6.1 Precipitation

Precipitation-quantity, duration, and intensity data were collected in the Field-Site 2 study area. The precipitation gage recorded accumulated precipitation at 5-minute intervals using a rain gage equipped with an analog-digital recorder (ADR), which was sensitive to precipitation amounts as little as 0.014 in. The precipitation gage was operational for the entire study period. Precipitation data were processed and stored in a computer data file at the USGS office in Lemoyne, Pennsylvania, for data analysis. Data collected at the field site were compared with long-term data collected at the National Oceanic and Atmospheric Administration (NOAA) precipitation station at Ephrata, Pennsylvania, and compared with record for the corresponding time period to estimate missing record.

Precipitation-quality samples were collected in April of 1986-89 and in October 1988. Samples were collected using a 13-inch glass funnel which collected precipitation into a glass jar that was packed in ice to keep the sample chilled to 4 °C. Precipitation samples were analyzed for dissolved nitrogen species and phosphorus by the PaDER laboratory in Harrisburg, Pennsylvania.

6.10.6.2 Agricultural activities

The USGS generally collected agricultural-activity data monthly from the farmer at Field-Site 2. Agricultural-activity data included timing, location, and amounts of commercial fertilizer, manure applications, and cultivation, planting, and harvesting information.

6.10.6.3 Soils

Soil-sample cores were collected at Field-Site 2 during the spring, summer, and fall of each year by personnel of the Pennsylvania State University, College of Agriculture.

Spring and fall samples were collected to depths of 4 ft using a hydraulic core press. Each four foot sample was a composite of three cores collected within an area of about 30 square feet. After collection, the three four-foot cores were split into four increments of 0-8, 8-24, 24-36, and 36-48 inches, composited, and then analyzed for soluble nitrate and soluble phosphorus. Soil analyses were performed at the Penn State Soils and Environmental Chemistry Laboratory, State College, Pennsylvania.

Summer samples were collected by hand to depths of 2 feet when crops grew too high to operate the hydraulic soil sampling equipment. After collection the two-foot cores were split into 2 increments of 0-8 and 8-24 inches, and analyzed for soluble nitrate and soluble phosphorus.

Samplings to depths of 8 feet were conducted in spring of 1989 and 1990. In addition to the standard four foot procedures, the deep cores were split into two additional increments of 48-72 and 72-96 inches for analysis.

6.10.6.4 Surface-runoff quantity and quality

Surface runoff from the 27 acres with pipe-outlet terraces at the site was routed through a 6-in. Parshall flume located beside a gage (USGS number 01576335) station at the base of the field. Water levels in the flume were measured with a graphic-stage recorder and an analog digital recorder (ADR). Runoff samples were collected with a float/stage-triggered PS-69 automatic-pumping sampler that was modified to keep samples chilled using a refrigeration unit. Runoff samples were collected at 30-minute intervals at stages

above 0.05 ft in the flume; the automatic sampler did not sample at stages below 0.05 ft. Perforated intakes for the automatic sampler were positioned in the center of the flume. The time of sample collection was recorded using an event marker that was triggered to mark the graphic discharge record when the sampling pump was engaged.

6.10.6.5 Ground-water quantity and quality

Fourteen wells and a spring were monitored at the site to aid in the characterization of site hydrogeology and to provide ground-water quality sampling points (table 6-12). Thirteen of the wells were drilled for this project using air-rotary drilling methods; the remaining well was an existing hand-dug well. Wells drilled for the project were cased to solid bedrock then continued as uncased holes into the unconfined carbonate-rock aquifer. Wells were cased with 6-inch steel casing, pressure-grouted, and surface-sealed with bentonite. Continuous water levels were recorded through the study period at six wells, and intermittent water-level measurements were made at other wells.

Water-quality monitoring was conducted at six wells that were equipped with continuous water-level recorders, and at the spring. Water from five wells and the spring were was sampled monthly and analyzed for specific conductance and concentrations of nutrients during nonrecharge periods and more frequently during several storm-recharge periods annually. Water from the remaining well was sampled quarterly and analyzed for specific conductance and concentrations of nutrients. In May 1986, ground-water samples from eight wells were collected and analyzed for concentrations of dissolved oxygen and major ions; water temperature was also measured. Prior to sampling, all wells except LN 1677 were pumped until water levels were about 5-ft below the sampling depth. After water levels recovered to the sampling depth, ground-water samples were collected using a Kemmerer-type point sampler. Well LN 1677 was not pumped prior to sampling because access to the well was restricted during the growing season, and because analyses of samples collected prior to and after pumping indicated little change in water quality.

Table 6-12.--Field-Site 2 study area ground-water data-collection locations and descriptions

[ft, depth in feet from land surface; NA, not applicable; --, no data; N, nutrient data only; NWL, nutrient and water-level data; +I, major-ion data; <, less than]

U.S. Geological Survey identification number	Latitude	Longitude	Total depth of well (feet)	Depth of bottom of casing (overburden) (feet)	Depth to bedrock (feet)	Bedrock elevation (feet)	Estimated specific capacity [(gal/min)/ft]	Type of data collected	Sampling depth (feet)
LN SP61	40°11'52"	76°10'53"	spring	NA	0	--	20	N+I	NA
LN 1667	40°11'52"	76°10'55"	unknown	--	--	--	20	N+I	From pump
LN 1669	40°11'49"	76°10'55"	100	11	6.5	352	<1	NWL+I	85
LN 1670	40°11'56"	76°10'57"	75	9.8	5.5	361	<1	NWL+I	65
LN 1671	40°11'52"	76°10'58"	28	18.8	13	342	<1	NWL	--
LN 1672	40°11'52"	76°11'05"	100	10.9	10	370	<1	NWL	--
LN 1673	40°11'48"	76°11'03"	46	13.8	12	368	<1	NWL+I	35
LN 1674	40°11'45"	76°11'15"	125	25.2	19	396	<1	NWL	35
LN 1675	40°11'50"	76°11'07"	55	17.2	14	374	<1	NWL	--
LN 1676	40°11'52"	76°11'01"	40	8.8	11	356	<1	NWL+I	35
LN 1677	40°11'56"	76°11'05"	50	30.0	28	349	20	NWL+I	35
LN 1679	40°11'52"	76°10'57"	60	13.4	10	354	20	NWL+I	35
LN 1680	40°11'56"	76°11'09"	60	7.8	7	375	<1	NWL	--
LN 1681	40°11'47"	76°11'08"	60	8.8	8	400	<1	NWL	35
LN 1682	40°11'48"	76°10'59"	350	18.6	18	350	<1	NWL+I	35

6.10.7 Data Analysis

6.10.7.1 Soils

Soil-nutrient concentration data were analyzed to investigate soil reserves of soluble nitrate nitrogen and phosphorus and to determine the effect of these reserves on water quality. The relation between soil-nutrient concentrations and seasonal agricultural activities was examined by plotting median concentrations of soluble nitrate nitrogen and phosphorus against sampling depth by date. Random events, such as a pre-study spill of anhydrous ammonia, were investigated to determine if they might be affecting surface- and ground-water quality at the site.

6.10.7.2 Surface runoff

Surface-runoff discharge was determined by using the measured gage-height record and converting gage heights to discharge with a standard rating for the flume. The flume rating was checked with field measurements of discharge using a pygmy current meter.

Graphs and regression techniques were used to identify variables that explained seasonal variations in the quantity of surface runoff. Runoff data were grouped by soil condition (thawed or frozen) to improve correlations between precipitation quantity and runoff quantity.

A number of methods were used to characterize the quality of surface runoff and to evaluate changes measured in the quality of surface runoff at Field-Site 2.

The annual loads were compared from year to year. Estimates of suspended sediment and nutrient loads for unsampled runoff events were calculated using regression equations derived from log-transformed suspended-sediment and nutrient loads versus log-transformed total runoff relations for sampled runoff events. Data for estimated and sampled individual runoff events were summed to estimate the monthly and annual loads.

Mean storm concentrations and loads of nutrients and sediment from data collected prior to and during the implementation of nutrient management were compared using the Mann-Whitney test, regression analysis, and analysis of covariance. Flow-weighted mean storm concentrations and loads were calculated from continuous graphs of discharge and constituent concentrations constructed using recorded stage and laboratory data from the discrete storm samples analyses. Flow-weighted mean event concentrations (C_s) and event loads (L_s) were calculated using the same method described for Field-Site 1 in section 6.9.7.1 in this report.

The quality of surface runoff was related to climate and agricultural activities. Graphs were drawn and regression statistics were computed to explain the changes in mean-storm nutrient concentrations. Variables that were considered to explain the change were precipitation, antecedent soil-moisture conditions, nutrient applications, and factors affecting nutrient availability. A quantitative relation was developed between nutrient concentrations and number of days since the previous nutrient application using data collected during thawed-soil conditions.

6.10.7.3 Groundwater

Aquifer properties, ground-water occurrence and flow, and ground-water quality were investigated as parts of the Field-Site 2 study.

Although a thorough investigation of aquifer properties was not made for this study, estimates of specific yield, specific capacities, and transmissivity were made, and occurrence and flow of ground water was analyzed.

The specific yield of the water-bearing bedrock and regolith was estimated from rises in water levels during periods of negligible evapotranspiration and high soil-water saturation using a method described by Gerhart (1986). This is the same method used to determine specific yield at Field-Site 1 (section 6.9.7.2, this report).

Specific capacities of 13 wells drilled at the site were calculated based on estimates made by the driller and visual observations of the flow through an existing hand-dug well. Determinations were made by dividing the discharge of water from the well by the drawdown of the water level within the well.

Transmissivity was estimated from the water-table configuration and Darcy's Law. For ground-water flow through a unit width of aquifer, Darcy's Law states:

$$Q = T(dh/dl) \qquad (6)$$

where Q = discharge or ground-water flow rate, in cubic feet per day;
T = transmissivity of the aquifer, in feet squared per day; and
dh/dl = the hydraulic gradient (water-table slope), in feet per foot.

Therefore, transmissivity was computed by rearranging and solving equation (6):

$$T = Q/(dh/dl) \qquad (7)$$

Additional estimates of transmissivity were made using techniques described by Rorabaugh (1960). Ground-water hydrograph recession slopes are used to calculate estimates of aquifer diffusivity. The formula used for calculating diffusivity is:

$$T/S = 0.933a^2\log((h_1/h_2)/(t_2 - t_1)) \qquad (8)$$

where T = transmissivity, in feet squared per day;
S = storage (dimensionless coefficient);
0.933 = constant to convert from base e to base 10;
a = 1/2 the width of the aquifer, in feet;
h = water table altitude, in feet;
t = time, in days; and
$(h_1/h_2)/(t_2-t_1)$ = the slope of the regression line for the period of the recession using semi-log paper.

Ground-water recharge was estimated from rises in water levels in observation wells which showed responses during storms in conjunction with computed specific yields using methods developed by Gerhart (1986). Monthly and annual ground-water discharges were assumed to be equal to recharge because storage times are generally small in the aquifer.

Water-table maps were analyzed to determine changes in the occurrence and flow directions of the multiple shallow ground-water drainage basins at the site. Estimates of the magnitude of ground-water movement across the field-site boundaries and tests of the estimated transmissivity values were made by constructing a ground-water flow model of the hillslope within which the site is located. McDonald and Harbaugh's (1984) finite-difference model was used to simulate the hillslope as a two-dimensional, steady-state flow system in the x-y plane.

Ground-water quality samples were separated into groups of either recharge or nonrecharge samples. Samples were considered to be recharge samples due to hydrologic effects described by Keith and others (1983). Recharge water-level altitude refers to the altitude of the water table less than one week after a (minimum) 0.3 foot water-level rise. Nonrecharge water-level altitude refers to the altitude of the water table at the site at all other times. Nonrecharge and recharge sample groups were assessed to determine variations in ground-water quality during short periods of recharge, and recharge data were compared to nonrecharge data. Recharge data were also studied to determine the effects of climate and agricultural activities on the overall quality of the water in the ground-water system.

Samples were analyzed for various nitrogen species to determine variations in the chemical composition of the ground water. Boxplots were used to characterize the ground-water quality by showing the distribution of minimum, median, and maximum specific conductances, and concentrations of dissolved phosphorus, ammonia plus organic nitrogen, nitrate plus nitrite, and nitrogen in the samples that were analyzed. Concentrations of nitrate nitrogen in samples were compared to the U.S. Environmental Protection Agency drinking-water health advisory and maximum contaminant level.

The relationships between ground-water quality and land use, agricultural activities, and recharge at Field-Site 2 were investigated. For the purpose of the study, estimates of surface areas where nitrogen

applied to fields can influence the water quality of the well, were made by first locating a primary flow line upgradient from five wells as indicated by analyzing the heads suggested by the slope of the water-table surface, and flow directions indicated by a two-dimensional ground-water model. Flow lines were expanded using a 2:1 (roughly 25 degree) ratio of longitudinal to lateral dispersion due to processes discussed by Bouwer (1978). Contributing areas were arbitrarily confined to a distance of approximately 1,000 ft upgradient from each well to determine areas of maximum influence.

The effect of surface-applied materials on ground-water quality during the percolation of recharge was shown by plotting times of precipitation, applications of manure and commercial fertilizer, and concentrations of nitrate in groundwater for the entire study period. Effects of individual recharge events were noted after making plots showing the relation of precipitation, changes in water levels, and concentrations of nitrate.

The Wilcoxon-Mann-Whitney median test was used to detect changes in ground-water nitrate concentrations prior to and after the implementation of nutrient management.

Statistical relations between changes in amount of nitrogen applied to contributing areas upgradient of each well and changes in concentrations of nitrate in ground water were determined by testing for time-lagged correlations using a Spearman Rank Correlation procedure.

Annual nitrogen loads were computed to determine the amount of nitrogen in ground water crossing site boundaries, and were summed totals of monthly loads that were computed using the equation:

$$(A + B)(C)(D)(E)(F) = G \qquad (9)$$

where A = volume of ground-water recharge entering western boundary, in liters;
B = volume of ground water entering the site from precipitation, in liters;
C = proportional percentage of ground water estimated to discharge across a site boundary;
D = monthly fraction of annual discharge;
E = monthly nitrate concentration of a sample (or samples) collected to characterize water quality;
F = milligram to pound conversion factor (2.205×10^{-6}); and
G = monthly nitrogen load from site across boundary, in pounds.

6.10.7.4 Hydrologic budget

A hydrologic budget for Field-Site 2 was estimated from measurements of runoff and estimates of ground-water recharge. Precipitation at the site is equal to runoff plus ground-water recharge plus evapotranspiration. Ground-water storage was assumed to equal zero on an annual basis. Normal precipitation was assumed to be equal to that measured at the NOAA station in Ephrata. Runoff was measured at the site. Recharge was estimated as discussed in section 6.10.7.3, and evapotranspiration was the residual term used to balance the equation.

6.10.7.5 Nitrogen addition and removal estimates

Quantities of nitrogen added to the site in manure fertilizer, commercial fertilizer, precipitation, and ground-water inflow, and quantities of nitrogen removed from the site by harvested crops, in surface-water discharge, in ground-water discharge, and by nitrogen volatilization were estimated for each year of the study period.

Applied manure and commercial fertilizer nitrogen were calculated from reports obtained from the landowner listing volumes of fertilizers and manures applied in conjunction with results from laboratory analysis of manure samples.

Nitrogen from precipitation was estimated based on samples collected April 15-17, 1986 and values reported by Lynch and others (1986).

Nitrogen from ground water was estimated from volumes of water predicted by the ground-water model and measured nitrate concentrations.

Nitrogen used by crops was calculated from crop yield data and crop consumption estimates from the Penn State Extension Service (Robert Anderson, written commun., 1989).

Nitrogen discharged in groundwater was estimated from measured nitrate concentration data and flows predicted by the ground-water model.

Nitrogen lost to volatilization was estimated from information published by Pionke and Urban (1985), P.L. Lietman, U.S. Geological Survey, written commun. (1990), Penn State Agronomy Guide (1989), and Smith and Peterson (1982).

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7.0 EVALUATION OF BEST-MANAGEMENT-PRACTICE/WATER-QUALITY STUDIES[1]

Results of data collection and data analysis for the water-quality study areas--the regional area, the small watershed basin, and two field sites--are discussed in this chapter. Included are characterizations of each of the sites in terms of precipitation, agricultural activities, soils, and surface- and ground-water quality where applicable. (General site descriptions and maps can be found in Chapter 6.) Also included are the results of statistical evaluation of the effects of agricultural best-management practices on water quality, including agricultural-activity/water-quality relationships. Interpretations of the data are made, where appropriate, based on preliminary data analyses and are subject to change pending additional data analysis and peer review.

Reports on monitoring strategy site characterizations, and the effects of BMPs on water quality for the project have been or will be published. Appendix F lists all reports by USGS and PaDER authors which are published, approved by USGS for publication, in the USGS review process, or in draft.

In this chapter, all concentrations of nutrients are expressed in their elemental form. That is, ammonia, organic nitrogen, nitrate, and nitrite are all expressed as nitrogen, and phosphorus is expressed as phosphorus.

7.1 FINDINGS AND RECOMMENDATIONS

The following recommendations for the protection of water quality through agricultural management practices are suggested with the note that, while not necessarily limited to, they are made based upon the geologic, hydrologic, and agricultural conditions which existed at the Conestoga Headwaters study sites at the time of this investigation.

GENERAL FINDING: In areas underlain by carbonate rock, ground water and base flow contribute a large portion of the water discharged from a site.

Site Specific Findings

- REGIONAL - For a 50-mi^2 basin, half underlain by carbonate rock, it was estimated that 75 percent of the total streamflow was base flow.
- SMALL WATERSHED - For a 5.8-square mile basin, half underlain by carbonate rock, 60 percent of the total streamflow was base flow.
- FIELD-SITE 1 - On the average, annually, about 15 percent of the 45 inches of precipitation was discharged as runoff, 35 percent as ground water, and the remainder as evapotranspiration.
- FIELD-SITE 2 - On the average, annually, less than 5 percent of the 42 inches of precipitation was discharged as runoff, about 45 percent as ground water, and the remainder as evapotranspiration.

RECOMMENDATION: BMP's implemented in carbonate areas should target ground water.

[1] Principal contributors to this chapter were Patricia Lietman, Edward Koerkle, David Hall, and David Fishel of the U.S. Geological Survey, and Mary Jo Brown of the Pennsylvania Department of Environmental Resources.

GENERAL FINDING: Ground water and stream base flow (sustained by ground-water discharge) in carbonate areas is highly susceptible to agricultural nonpoint-source contamination.

Site Specific Findings

■ REGIONAL - Surface water from predominantly carbonate, agricultural areas contained higher base-flow nitrate and atrazine concentrations than surface water from predominantly noncarbonate, nonagricultural areas.

- In a 50 square-mile agricultural basin, half underlain by carbonate rock, about 65 percent of the stream nitrogen load was discharged as base flow.
- Of 28 wells sampled throughout the year in carbonate, agricultural areas, more than 45 percent of the water samples had concentrations of nitrate exceeding the EPA drinking-water criterion of 10 mg/L as N, and more than 35 percent had detectable atrazine concentrations (greater than or equal to 0.2 mg/L).

■ SMALL WATERSHED - In a 5.8 square-mile watershed, half underlain by carbonate rock, base-flow nitrate concentrations increased as the stream flowed through the carbonate agricultural area.

- Base-flow nitrate load accounted for about 65 percent of the total nitrogen load discharged from the watershed.

■ FIELD-SITE 1 - Water from all 8 of the sampled wells and the spring sometimes or always contained nitrate concentrations exceeding 10 mg/L as N and 5 of 6 sampled wells and the spring sometimes contained detectable concentrations of triazine herbicides.

- About 20 percent of the nitrogen leaving the site was discharged in ground water.

■ FIELD-SITE 2 - Water from 8 of 10 sampled wells and the spring often or always contained nitrate concentrations exceeding 10 mg/L as N.

- About 40 percent of the nitrogen leaving the site was discharged with ground water.
- Rapid nitrate transport in this carbonate basin produced faster and more pronounced changes in ground-water concentrations than would probably result in other geologic settings. Changes in the nitrate concentrations of ground-water samples lagged approximately 4 to 19 months behind changes in applications.

RECOMMENDATION: BMPs implemented in carbonate areas need to specifically address transport of contaminants to ground water.

RECOMMENDATION: Reduce herbicide application rates or select formulations which have greater resistance to leaching than the triazine herbicides.

GENERAL FINDING: Land-surface changes caused by BMP and non-BMP factors can affect the relative quantities of surface and ground water, and can interfere with reduction of agricultural nonpoint-source contamination.

Site Specific Findings

■ FIELD-SITE 1 - Pipe-outlet terracing increased the amount of rainfall needed for the onset of runoff, however, the relation between the amounts of runoff and precipitation did not change significantly after terracing.

- Terracing did not significantly change quantity of recharge or the annual average water-table altitude for the site.

- FIELD-SITE 2 - The amounts of runoff relative to precipitation increased significantly when tillage practices changed from predominantly no till to minimum till and winter crop covers were no longer planted.

RECOMMENDATION: Farm-management practices, including BMPs, need to be selected in context of their overall effect on both surface and ground-water systems.

GENERAL FINDING: Suspended sediment and phosphorus were predominantly transported with runoff.

Site Specific Findings

- REGIONAL - For a 50-square mile basin, half underlain by carbonate rock, about 95 percent of the sediment load and 75 percent of the phosphorus load was discharged from the basin during stormflow.
- SMALL WATERSHED - For a 5.8-square mile basin, half underlain by carbonate rock, an estimated 90 percent of the sediment load and 75 percent of the phosphorus load was transported with stormflow.
- FIELD SITES 1 AND 2 - For the 22 and 48-acre field sites, all the sediment and essentially all the phosphorus left the site with runoff. Median ground-water phosphorus concentrations were less than the 0.1 milligram/liter detection limit.

RECOMMENDATION: Where sediment and phosphorus are contaminating water supplies, BMPs should be targeted to control surface runoff.

GENERAL FINDING: Frozen soil conditions were a major factor affecting runoff water quality.

Site Specific Findings

- FIELD-SITE 1 - Runoff from storms on frozen ground generally carried substantially less suspended-sediment and substantially more nitrogen in runoff than storms occurring when the ground was thawed.
- FIELD-SITE 2 - Storms on frozen ground accounted for up to about 80 percent of the discharge, 75 percent of the total nitrogen, and 75 percent of the total phosphorus annual load in runoff from 27 acres of pipe-outlet terraces.

RECOMMENDATION: Elimination of nutrient applications on frozen or partially frozen soil needs to be strongly emphasized as part of a nutrient-management program.

GENERAL FINDING: Terracing was effective in controlling sediment losses from a field, but relatively ineffective in controlling nutrient losses to surface- and ground-water.

Site Specific Findings

- FIELD-SITE 1 - Mean suspended-sediment concentrations in runoff decreased after terracing and a period of stabilization. Decreases were larger after the crop changes planned as part of the terracing BMP were made. The suspended-sediment yield exceeded the erosion factor T of 4 (tons/acre)/yr before but not after terracing.
- No overall significant change was found in total nitrogen or phosphorus concentrations in runoff after terracing, although nitrate concentrations in runoff increased after terracing.

- Limited data suggest that fine sediment particles, which continued to be transported in runoff after terracing, transported most of the phosphorus.
- Ground-water nitrate concentrations increased in water from three wells and the spring after terracing.

RECOMMENDATION: In pipe-outlet terrace systems secondary sediment-control measures are recommended to reduce the losses of fine soil particles and any associated phosphorus.

RECOMMENDATION: Nutrient management should be implemented simultaneously with terracing to diminish the possibility of increased ground-water contamination.

RECOMMENDATION: All parts of the planned erosion-control BMP should be implemented for maximum BMP effectiveness.

GENERAL FINDING: The effectiveness of nutrient management in reducing nutrient concentrations in surface and ground water was dependent upon the level of reduction in nutrient applications.

Site Specific Findings

- ■ SMALL WATERSHED - Nutrient-management practices implemented on 90 percent of the agricultural land in a 1.42 square-mile subbasin reduced average annual nitrogen inputs about 15 percent and resulted in no significant change in median base-flow dissolved nitrate, total ammonia plus organic nitrogen, and total phosphorus concentrations after implementation. Median base-flow dissolved ammonia concentrations decreased less than 0.1 milligrams per liter. However, nitrate concentrations exceeding 10 mg/L as N were found in 4 percent of the monthly base-flow samples collected prior to nutrient management and in 2 percent of the samples collected during nutrient management.
- Nutrient-management practices were implemented on 45 percent of the agricultural land in a 5.82 square-mile basin. Nitrate concentrations exceeding 10 mg/L as N were found in 3 percent of the monthly base-flow samples collected prior to nutrient management and in 9 percent of the samples collected during nutrient management.
- ■ FIELD-SITE 1 - Nutrient management, a planned BMP at the site, resulted in only an average of about 10 percent less nitrogen and phosphorus being applied to the site.
- Total nitrogen and phosphorus concentrations in runoff did not change significantly during the study.
- Although nutrient management did not result in substantially decreased nutrient applications to the site, decreased nutrient applications resulting from a crop change from predominantly corn to alfalfa upgradient from two wells. Ground-water nitrate concentrations at these two wells decreased after the crop change.
- ■ FIELD-SITE 2 - The implementation of nutrient management resulted in a reduction of 45 percent in the nitrogen and phosphorus applied to the site in the first two years of the post-BMP period (1987-88) when surface runoff was monitored, and a reduction of about 20 percent in the nitrogen and about 30 percent in the phosphorus applied to the site for the entire post-BMP period (1987-90) when ground water was monitored.
- Nitrate concentrations in runoff decreased significantly after nutrient management was implemented, probably as a result of reduced nitrogen applications although total nitrogen or phosphorus concentrations did not change significantly.
- Median concentrations of nitrate in shallow ground water from four wells decreased from 8 to 32 percent after the implementation of nutrient management.

- Ground-water nitrogen loads decreased from about 300 to 200 pounds of nitrogen per million gallons of ground-water discharge after implementation of nutrient management.

RECOMMENDATION: Substantial reductions in nutrient applications need to be recommended in the nutrient management plan and recommendations need to be closely followed on a continuing basis to significantly improve water quality.

RECOMMENDATION: Implementation of nutrient management is recommended as the most effective approach to improve ground-water quality where moderate to severe nonpoint source nutrient contamination of groundwater exists.

GENERAL FINDING: Manure applications to farmland, traditionally for disposal, have been underestimated as a source of nutrient inputs to the watershed.

Site Specific Findings

- SMALL WATERSHED - Land-surface applications of animal manures contributed about 70 percent of the estimated average annual total nitrogen input to the nutrient-management subbasin.
- FIELD-SITE 1 - Animal manure contributed about 90 percent of the estimated average annual total nitrogen input.
- FIELD-SITE 2 - Animal manure contributed about 95 percent of the estimated average annual total nitrogen input.

RECOMMENDATION: Reductions in animal density, manure export, and/or land-use changes are needed to reduce nutrient inputs to the water system.

GENERAL RECOMMENDATION: Efforts need to be made to develop new or improve existing BMPs. Reduction of nutrient losses to surface water and ground water should be the explicit goal of such BMPs.

GENERAL RECOMMENDATION: More research is needed to define realistic water-quality goals in carbonate areas, and to determine the impact of water of a quality meeting those goals on designated uses.

7.2 REGIONAL STUDY AREA

7.2.1 Regional Precipitation

Precipitation in the regional study area was less than the long-term normals of 43 and 42 in. of precipitation for Ephrata and Morgantown, respectively, and at Martindale precipitation was nearly 10 in. below normal. Precipitation at the Ephrata and Morgantown NOAA stations was 13 percent and 12 percent below the normals, respectively.

Precipitation at all of the stations was highly variable during the period April 1982 through September 1983 as reflected in figure 7.2-1 and table 7.2-1. Monthly precipitation ranged from 0.41 in. at Martindale in July 1983 to 7.77 in. at Churchtown in April 1983 (fig. 7.2-1) and total precipitation differed by more than 6.0 in. between Martindale and Churchtown (table 7.2-1).

Seasonal variations in precipitation also were evident at the stations. Precipitation was above normal during the growing season and below normal during the nongrowing season at the NOAA stations at Ephrata and Morgantown. Precipitation during the growing season (April through September) was more than 5 in. greater than during the nongrowing season at Martindale, Morgantown, and Churchtown. Long-term records indicate that precipitation during the growing season is normally more than 5 in. greater than precipitation during the nongrowing season.

7.2.2 Regional Agricultural Activities

Early during the establishment of the data-collection network for the Regional Study area, and subsequent collection of water-quality data, it was realized that implementation of agricultural-management practices would need to gain sudden wide-spread acceptance if the quality of water was to change at the outflows of the 188 mi^2 Conestoga River Headwaters within the time frame of the project. But, there was a reluctance on the part of landowners for implementation, especially since the costs were often high, and because the effects of any given "best-management practice" on surface water and ground water were unknown.

Table 7.2-1.--Variations in precipitation within the Regional Study area and between measured (October 1982 through September 1983) and normal (1951-80) precipitation at the Ephrata and Morgantown NOAA stations

[Precipitation, in inches]

Station	Growing season (April through September)	Nongrowing season (January through March and October through December)	Total
Martindale	20.25	12.48	32.73
Morgantown	20.79	13.13	33.92
Churchtown	22.48	16.83	39.31
NOAA STATIONS			
Ephrata			
Measured	22.63	15.08[1]	37.71
Normal	24.32	18.83	43.15
Morgantown			
Measured	20.55	16.68	37.23
Normal	23.69	18.58	42.27

[1] No data collected in December 1982.

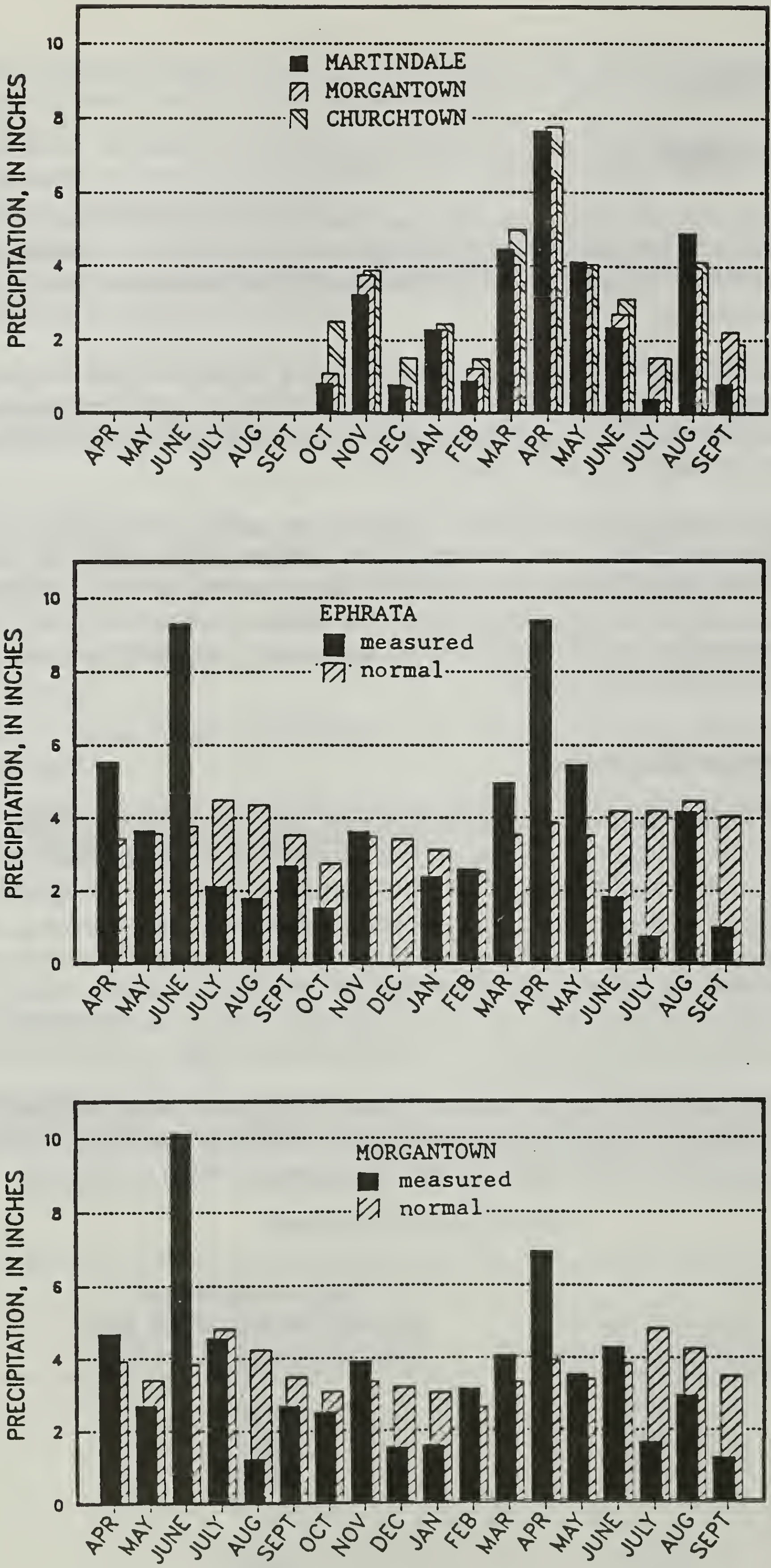


Figure 7.2-1.--Precipitation measured at Martindale, Morgantown, and Churchtown Regional Network precipitation gages, and measured and normal precipitation for National Oceanic and Atmospheric Administration stations at Ephrata and Morgantown.

Agricultural-activity data collected in the 188 mi^2 Conestoga Headwaters was of a general nature and included the number of cooperating farms, date that cooperation started, and expected savings as a result of that cooperation and can be found in other sections of this report.

7.2.3 Regional Surface Water Quantity and Quality

For this project, the agricultural chemicals of primary concern for transport to the water system were nitrogen, phosphorus, and selected herbicides. Suspended sediment and bacteria from agricultural activities due to erosion and manure, respectively, may also be transported to the water system.

Statistical summaries of the surface-water-quality data for base flow at 4 sites, and stormflow at 2 sites are shown in tables 7.2-2 and 7.2-3, respectively. Two of these sites, the Conestoga River near Terre Hill and the Little Conestoga Creek near Churchtown, have drainage areas that are about half in carbonate rock. The other two sites, Muddy Creek near Martindale and Cocalico Creek near Ephrata, have drainage areas nearly entirely in noncarbonate rock. The difference in the geology of the drainage basins is reflected in the water-quality data. Calcium and magnesium concentrations, and therefore hardness, and alkalinity are about twice as high for the basins draining large, carbonate areas.

Table 7.2-4 summarizes the streamflow, nitrogen, phosphorus, and suspended-sediment data for a 1-year period at the Conestoga River near Terre Hill site. The Terre Hill site was chosen for more detailed data collection because of the carbonate rock influence, and because agricultural activities are intensively concentrated in carbonate areas. This data shows that about 75 percent of the total streamflow was base flow, sustained by ground-water discharge. Nitrate associated with the ground water contributes a large portion of the total nitrogen load, about two-thirds, to the stream. Phosphorus and suspended-sediment loads are primarily associated with stormflow due to surface runoff. Estimated stormflow contributions of phosphorus were about 73 percent and of sediment about 94 percent of the total annual stream load.

Because base flow is such a large component of streamflow, total nitrate and atrazine concentrations in base-flow samples were examined more closely. Figures 7.2-2 and 7.2-3 show that water from the two sites underlain about half by carbonate geology, and located where farming is concentrated had higher nitrate and atrazine concentrations than the other two sites. The highest nitrate concentrations at all sites occurred during the winter months, and in the early summer following heavy fertilizer applications. The highest atrazine concentrations at all sites occurred in June soon after application, which is generally only made once a year at corn planting time.

7.2.4 Regional Ground Water Quantity and Quality

The ground-water-quality data for the regional network is discussed in a publication by Fishel and Lietman, 1986.

Water levels in the wells sampled for ground-water quality (fig. 6-2) during the four sampling periods are summarized in table 7.2-5. The water-level data shows that a relatively shallow water table (a median of 36 feet below surface for all samples) was sampled. This conforms with the targeted shallow water table for sampling. Generally, the water levels during the fall were substantially lower than during the spring or summer sampling periods, which were similar. The variation in water level between seasons also indicates that the water table is responsive to precipitation and supports evidence from previous studies of a good vertical connection between the surface and water table.

Water quality of samples collected from 75 of the wells in the Regional Study area in the fall of 1982 is summarized in table 7.2-6. The major ions and associated characteristics, and other constituents of concern are grouped by wells drilled in carbonate and noncarbonate formations. Rock-type classifications were made by locating the wells on detailed geologic/topographic maps. If the wells are located near formation intersects, it is possible that the ground-water from that well may be influenced by another rock type. Generally, water from wells located in carbonate formations had higher pH and specific-conductance values, alkalinities, hardness, and concentrations of calcium and magnesium than were found in water from wells in noncarbonate formations, probably due to the dissolution of the carbonate bedrock.

Table 7.2-2.--Statistical summary of the quality of base flow from April 1982 to March 1983

[Water temperature in degrees Celsius; discharge in cubic feet per second; specific conductance in microsiemens per centimeter at 25 degrees Celsius; concentrations in milligrams per liter except pesticides, which are in micrograms per liter; mi^2, square miles; <, less than; --, none detected; –, no data]

Water-quality constituent	Descriptive statistics			
	Sample size	Maximum	Minimum	Median
Station number: 01576085 Station name: Little Conestoga Creek nr Churchtown, PA Drainage area: 5.82 mi^2				
Water temperature	10	28.5	1.0	14.8
Discharge	9	13	1.1	3.0
Specific conductance	10	564	362	441
Oxygen, dissolved	9	14.6	4.6	8.8
pH	10	8.8	7.8	8.0
Alkalinity, (as $CaCO_3$)	10	157	119	140
Acidity, total (as $CaCO_3$)	7	6.0	.0	2.0
Nitrogen, total (as N)	8	11.	5.5	9.8
Nitrogen, dissolved (as N)	2	9.6	9.0	–
Nitrogen, organic total (as N)	9	1.6	.13	.93
Nitrogen, organic dissolved (as N)	8	1.6	.14	.50
Nitrogen, ammonia dissolved (as N)	10	.26	.01	.08
Nitrogen, ammonia total (as N)	10	.27	.01	.12
Nitrogen, nitrite dissolved (as N)	10	.26	.03	.10
Nitrogen, nitrite total (as N)	10	.26	.03	.10
Nitrogen, nitrate dissolved (as N)	10	9.9	2.50	6.5
Nitrogen, nitrate total (as N)	10	9.9	2.80	7.1
Nitrogen, ammonia + organic, dissolved (as N)	8	1.7	.27	.60
Nitrogen, ammonia + organic, total (as N)	9	1.7	.40	1.1
Phosphorus, total (as P)	10	.50	.09	.28
Phosphorus, dissolved (as P)	10	.39	.05	.19
Phosphorus, dissolved ortho (as P)	10	.30	.04	.15
Hardness, total (as $CaCO_3$)	10	230	160	195
Calcium, dissolved (as Ca)	10	52	36	44
Magnesium, dissolved (as Mg)	10	24	16	20
Sodium, dissolved (as Na)	10	210	4.5	6.8
Potassium, dissolved (as K)	10	15	2.2	4.8
Chloride, dissolved (as Cl)	10	22	13	17
Sulfate, dissolved (as SO_4)	9	70	25	40
Coliform, fecal (colonies/100 mL)	10	76,000	100	7,150
Streptococci, fecal (colonies/100 mL)	9	47,000	160	8,700
Residue, dissolved at 180 °C	7	380	254	292
Sediment, suspended	9	232	5.0	52
Atrazine, total	9	1.0	<.2	*.2
Cyanazine, total	9	<.2	<.2	<.2
Propazine, total	9	<.2	<.2	<.2
Simazine, total	9	<.2	<.2	<.2
Station number: 01576105 Station name: Conestoga River near Terre Hill, PA Drainage area: 49.2 mi^2				
Water temperature	11	22.0	1.0	12
Discharge	11	89	16	29
Specific conductance	11	495	395	440
Oxygen, dissolved	11	16.0	7.0	11
pH	11	8.6	8.0	8.3
Alkalinity, (as $CaCO_3$)	11	172	120	151
Acidity, total (as $CaCO_3$)	11	20	.0	.0
Nitrogen, organic total (as N)	10	1.7	.21	.83
Nitrogen, organic dissolved (as N)	9	1.0	.07	.53
Nitrogen, ammonia dissolved (as N)	11	.15	--	*.06

Table 7.2-2.--Statistical summary of the quality of base flow from April 1982 to March 1983--Continued

[Water temperature in degrees Celsius; discharge in cubic feet per second; specific conductance in microsiemens per centimeter at 25 degrees Celsius; concentrations in milligrams per liter except pesticides, which are in micrograms per liter; mi^2, square miles; <, less than; –, none detected; –, no data]

Water-quality constituent	Descriptive statistics			
	Sample size	Maximum	Minimum	Median
Nitrogen, ammonia total (as N)	11	.15	–	*.07
Nitrogen, nitrite dissolved (as N)	11	.10	–	*.03
Nitrogen, nitrite total (as N)	11	.11	.01	.03
Nitrogen, nitrate dissolved (as N)	10	8.3	4.4	6.1
Nitrogen, nitrate total (as N)	11	8.7	4.4	6.1
Nitrogen, ammonia + organic, dissolved (as N)	10	1.1	.16	.58
Nitrogen, ammonia + organic, total (as N)	11	1.9	.26	1.1
Phosphorus, total (as P)	11	.26	.07	.14
Phosphorus, dissolved (as P)	11	.17	.05	.08
Phosphorus, dissolved ortho (as P)	10	.13	.03	.06
Hardness, total (as $CaCO_3$)	11	240	160	210
Calcium, dissolved (as Ca)	11	58	35	46
Magnesium, dissolved (as Mg)	11	24	16	22
Sodium, dissolved (as Na)	10	12	6.8	9.2
Potassium, dissolved (as K)	11	6.7	2.4	3.3
Chloride, dissolved (as Cl)	11	27	19	21
Sulfate, dissolved (as SO_4)	10	130	25	35
Coliform, fecal (colonies/100 mL)	11	9,200	23	1,300
Streptococci, fecal (colonies/100 mL)	11	17,000	240	3,100
Residue, dissolved at 180 °C	7	336	238	308
Sediment, suspended	10	82	12	46
Atrazine, total	10	.8	<.2	*.2
Cyanazine, total	10	<.2	<.2	<.2
Propazine, total	10	<.2	<.2	<.2
Simazine, total	10	.3	<.2	<.2
Station number: 01576240 Station name: Muddy Creek near Martindale, PA Drainage area: 49.3 mi^2				
Water temperature	10	24.5	1.0	14.2
Discharge	8	78	8.0	14
Specific conductance	10	560	230	275
Oxygen, dissolved	10	15.0	6.4	9.2
pH	10	8.4	7.6	8.0
Alkalinity, (as $CaCO_3$)	10	78	34	60
Acidity, total (as $CaCO_3$)	9	6.0	.0	3.0
Nitrogen, organic total (as N)	10	1.7	.27	.95
Nitrogen, organic dissolved (as N)	8	1.2	.08	.49
Nitrogen, ammonia dissolved (as N)	10	.15	.01	.08
Nitrogen, ammonia total (as N)	10	.16	.01	.08
Nitrogen, nitrite dissolved (as N)	10	.08	.01	.02
Nitrogen, nitrite total (as N)	10	.08	.01	.02
Nitrogen, nitrate dissolved (as N)	10	3.9	1.3	2.0
Nitrogen, nitrate total (as N)	10	3.9	1.3	2.0
Nitrogen, ammonia + organic, dissolved (as N)	8	1.2	.18	.60
Nitrogen, ammonia + organic, total (as N)	10	1.7	.37	1.1
Phosphorus, total (as P)	10	.29	.08	.18
Phosphorus, dissolved (as P)	10	.20	.05	.14
Phosphorus, dissolved ortho (as P)	8	.17	.04	.10
Hardness, total (as $CaCO_3$)	10	110	78	86
Calcium, dissolved (as Ca)	10	30	21	24
Magnesium, dissolved (as Mg)	10	8.3	6.1	6.7

Table 7.2-2.--Statistical summary of the quality of base flow from April 1982 to March 1983--Continued

[Water temperature in degrees Celsius; discharge in cubic feet per second; specific conductance in microsiemens per centimeter at 25 degrees Celsius; concentrations in milligrams per liter except pesticides, which are in micrograms per liter; mi^2, square miles; <, less than; --, none detected; –, no data]

Water-quality constituent	Descriptive statistics			
	Sample size	Maximum	Minimum	Median
Sodium, dissolved (as Na)	9	55	9.9	16
Potassium, dissolved (as K)	10	3.9	1.3	2.4
Chloride, dissolved (as Cl)	9	26	14	20
Sulfate, dissolved (as SO_4)	9	40	20	25
Coliform, fecal (colonies/100 mL)	10	50,000	48	1,150
Streptococci, fecal (colonies/100 mL)	10	9,700	420	1,420
Residue, dissolved at 180 °C	6	362	170	194
Sediment, suspended	10	46	10	14
Atrazine, total	9	<.2	<.2	<.2
Cyanazine, total	9	<.2	<.2	<.2
Propazine, total	9	<.2	<.2	<.2
Simazine, total	8	.6	<.2	*.3
Station number: 01576330 Station name: Cocalico Creek near Ephrata, PA Drainage area: 43.1 mi^2				
Water temperature	9	24.0	.5	12.0
Discharge	10	89	5.7	12
Specific conductance	10	350	218	254
Oxygen, dissolved	10	15.2	7.2	10.1
pH	10	8.4	7.6	8.1
Alkalinity, (as $CaCO_3$)	10	100	43	76
Acidity, total (as $CaCO_3$)	9	6.0	.0	2.0
Nitrogen, organic total (as N)	10	1.9	.05	.82
Nitrogen, organic dissolved (as N)	8	1.7	.00	.52
Nitrogen, ammonia dissolved (as N)	10	.13	.01	.06
Nitrogen, ammonia total (as N)	10	.13	.01	.06
Nitrogen, nitrite dissolved (as N)	10	.05	.01	.02
Nitrogen, nitrite total (as N)	10	.09	.01	.02
Nitrogen, nitrate dissolved (as N)	10	3.7	1.1	1.9
Nitrogen, nitrate total (as N)	10	3.9	1.1	2.2
Nitrogen, ammonia + organic, dissolved (as N)	8	1.8	.07	.58
Nitrogen, ammonia + organic, total (as N)	10	2.0	.12	.84
Phosphorus, total (as P)	10	.16	.05	.10
Phosphorus, dissolved (as P)	10	.10	.02	.06
Phosphorus, dissolved ortho (as P)	8	.06	.01	.04
Hardness, total (as $CaCO_3$)	10	140	78	105
Calcium, dissolved (as Ca)	10	40	24	31
Magnesium, dissolved (as Mg)	10	8.6	4.3	6.2
Sodium, dissolved (as Na)	9	20	5.6	8.1
Potassium, dissolved (as K)	10	3.9	1.3	2.0
Chloride, dissolved (as Cl)	7	21	12	16
Sulfate, dissolved (as SO_4)	9	40	15	25
Coliform, fecal (colonies/100 mL)	10	6,200	130	2,250
Streptococci, fecal (colonies/100 mL)	10	12,000	200	2,750
Residue, dissolved at 180 °C	6	196	130	179
Sediment, suspended	10	29	7.0	16
Atrazine, total	9	.3	<.2	<.2
Cyanazine, total	9	<.2	<.2	<.2
Propazine, total	9	<.2	<.2	<.2
Simazine, total	9	1.3	.1	.7

Table 7.2-3.--Statistical summary of the quality of storm flow from April 1982 to March 1983

[Water temperature in degrees Celsius; discharge in cubic feet per second; specific conductance in microsiemens per centimeter at 25 degrees Celsius; concentrations in milligrams per liter except pesticides, which are in micrograms per liter; mi^2, square miles; <, less than; --, none detected; –, no data]

Water-quality constituent	Descriptive statistics			
	Sample size	Maximum	Minimum	Median
Station number: 01576085 Station name: Little Conestoga Creek near Churchtown, PA Drainage area: 5.82 mi^2				
Discharge	64	322	.9	26
Specific conductance	11	444	158	330
pH	5	8.1	7.3	7.4
Nitrogen, organic total (as N)	50	9.7	.20	2.2
Nitrogen, organic dissolved (as N)	12	2.7	.17	1.0
Nitrogen, ammonia dissolved (as N)	14	.99	.03	.40
Nitrogen, ammonia total (as N)	50	2.3	.07	.48
Nitrogen, nitrite dissolved (as N)	14	.55	.02	.18
Nitrogen, nitrite total (as N)	51	.7	.01	.08
Nitrogen, nitrate dissolved (as N)	13	9.0	1.8	3.0
Nitrogen, nitrate total (as N)	50	10	1.3	3.2
Nitrogen, ammonia + organic, dissolved (as N)	12	3.4	.20	1.4
Nitrogen, ammonia + organic, total (as N)	51	12	.27	2.6
Phosphorus, total (as P)	51	10	.17	1.9
Phosphorus, dissolved (as P)	14	1.8	.13	.51
Phosphorus, ortho dissolved (as P)	13	1.0	.09	.43
Hardness, total (as $CaCO_3$)	13	190	61	110
Calcium, dissolved (as Ca)	13	45	15	26
Magnesium, dissolved (as Mg)	13	19	5.6	10
Sodium, dissolved (as Na)	13	7.8	1.9	4.9
Potassium, dissolved (as K)	13	40	2.3	6.0
Chloride, dissolved (as Cl)	12	24	4.0	16
Sulfate, dissolved (as SO_4)	12	75	15	32
Coliform, fecal (colonies/100 mL)	5	4,200,000	10,000	23,000
Streptococci, fecal (colonies/100mL)	5	10,000,000	9,200	61,000
Residue, dissolved at 180 °C	13	274	98	212
Sediment, suspended	67	5,990	18	75
Sediment (percent finer than 0.62 microns)	7	99	76	93
Alachlor, total	8	5.5	<.1	*.5
Atrazine, total	12	31	.2	.8
Cyanazine, total	12	32	<.2	*.2
Dieldrin, total	2	.04	.03	–
Metolachlor, total	8	3.1	<.1	*.5
Propazine, total	12	<.2	<.2	<.2
Simazine, total	12	1.3	<.2	*.2
Station number: 01576105 Station name: Conestoga River near Terre Hill, PA Drainage area: 49.2 mi^2				
Discharge	63	896	22	114
Nitrogen, total (as N)	7	18	4.7	7.1
Nitrogen, organic total (as N)	8	11	.0	.90
Nitrogen, ammonia dissolved (as N)	2	.46	.35	–
Nitrogen, ammonia total (as N)	8	1.3	.21	.3
Nitrogen, nitrite dissolved (as N)	2	.03	.03	–
Nitrogen, nitrite total (as N)	8	.40	.02	.04
Nitrogen, nitrate dissolved (as N)	2	4.8	3.3	–
Nitrogen, nitrate total (as N)	8	6.3	3.3	4.5
Nitrogen, ammonia + organic, dissolved (as N)	2	1.3	.86	–
Nitrogen, ammonia + organic, total (as N)	8	12	.36	1.2
Phosphorus, total (as P)	8	2.5	.20	1.7

Table 7.2-3.—Statistical summary of the quality of storm flow from April 1982 to March 1983—Continued

[Water temperature in degrees Celsius; discharge in cubic feet per second; specific conductance in microsiemens per centimeter at 25 degrees Celsius; concentrations in milligrams per liter except pesticides, which are in micrograms per liter; mi^2, square miles; <, less than; --, none detected; –, no data]

Water-quality constituent	Descriptive statistics			
	Sample size	Maximum	Minimum	Median
Phosphorus, dissolved (as P)	2	.36	.34	–
Phosphorus, ortho dissolved (as P)	2	.31	.24	–
Residue, dissolved at 180 °C	2	146	114	–
Sediment, suspended	92	1,300	28	80
Aldrin, total	3	.01	.01	–
Atrazine, total	4	<.2	<.2	<.2
Chlordane, total	3	.1	.1	.1
Cyanazine, total	4	<.2	<.2	<.2
DDD, total	3	.01	.01	.01
DDE, total	3	.01	.01	.01
DDT, total	3	.01	.01	.01
Diazinon, total	3	.01	.01	.01
Dieldrin, total	3	.01	.01	.01
Endosulfan, total	3	.01	.01	.01
Endrin, total	3	.01	.01	.01
Eth trith, total	3	.01	.01	.01
Ethion, total	3	.01	.01	.01
Heptachlor, total	3	.01	.01	.01
Hept epox, total	3	.01	.01	.04
Lindane, total	3	.03	.02	.02
Malathion, total	3	.01	.01	.01
Methoxychlor, total	3	.01	.01	.01
Met parth, total	3	.01	.01	.01
Met trith, total	3	.01	.01	–
Mirex, total	3	.01	.01	–
Parathion, total	3	.01	.01	–
PCB, total	3	.1	.1	.1
PCN, total	3	.1	.1	.1
Perthane, total	3	.1	.1	.1
Propazine, total	4	<.2	<.2	<.2
Silvex, total	3	.01	.01	.01
Simazine, total	4	.5	.4	.05
2,4-D, total	3	.02	.02	.02
2,4-DP, total	3	.01	.01	.01
2,4,5-T, total	3	.01	.01	.01

Table 7.2-4.--Streamflow and estimated annual total nitrogen, phosphorus, and suspended sediment concentrations and loads in the Conestoga River above Terre Hill (49.2 mi^2), May 1982 - April 1983

	Stormflow	Base flow	Total
Streamflow, in millions of gallons	4,000	11,800	15,800
Percent of total streamflow	25	75	100
Mean N concentration, in mg/L as N	10.8	7.3	--
N load, in tons per year	180	360	540
Percent of total N load	33	67	100
Mean P concentration, in mg/L as P	1.6	.2	--
P load, in tons per year	27	10	37
Percent of total P load	73	27	100
Mean suspended-sediment concentration, in mg/L	430	50	480
Suspended-sediment load, in tons per year	32,000	2,000	32,000
Percent of total suspended-sediment load	94	6	100

Table 7.2-5.--Summary statistics of water-level data for wells sampled in the Regional study area

[n, number of samples; Min, minimum; Max, maximum]

		Feet below land surface				
	n	Min	25%	Median	75%	Max
Fall 1982	40	11.6	30.4	42.8	57.2	124
Spring 1983	35	7.0	21.1	32.6	54.5	93.4
Summer 1983	53	10.0	26.1	34.0	53.4	99.5
Fall 1983	33	11.8	27.9	38.8	57.6	126

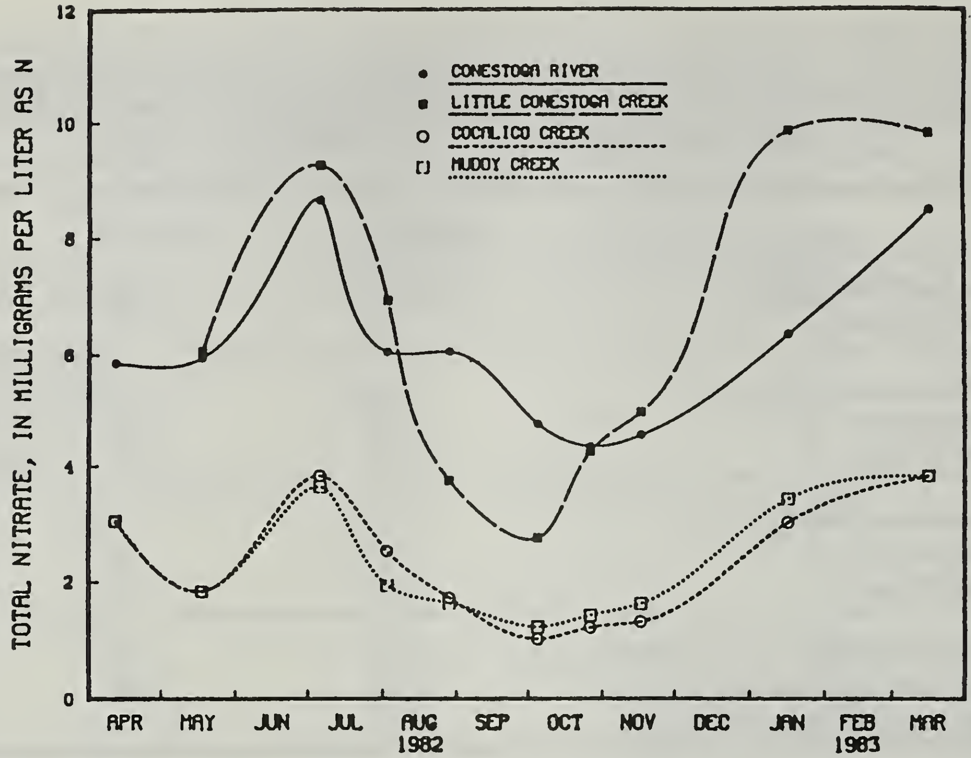


Figure 7.2-2.--Total nitrate concentrations in baseflow samples from the Regional Study Area surface-water sites.

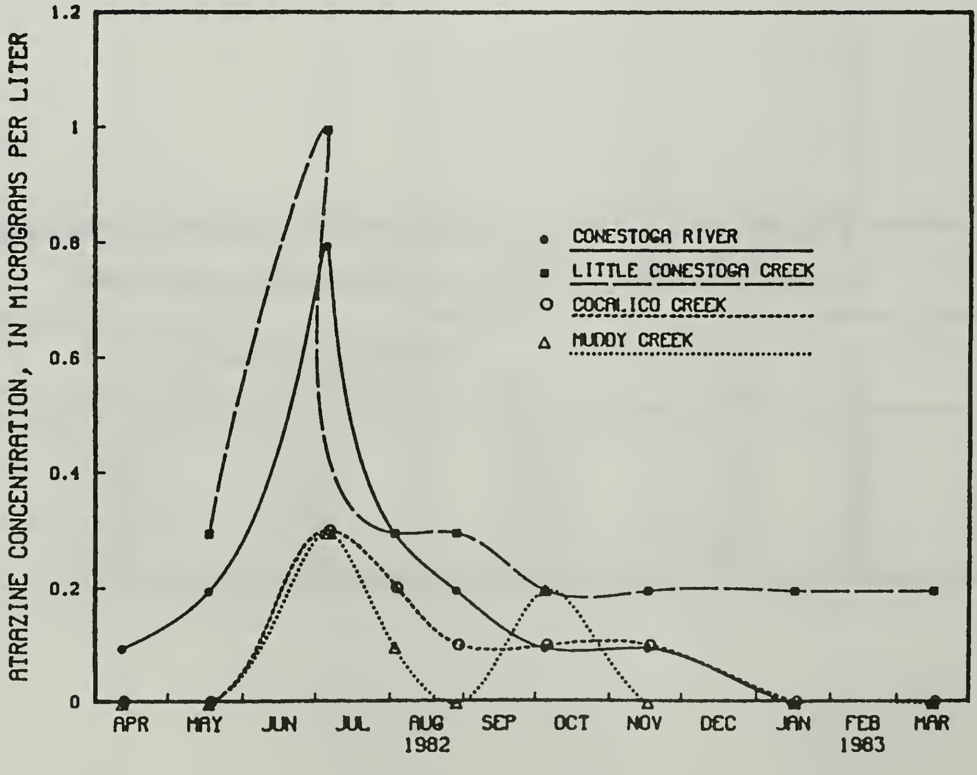


Figure 7.2-3.--Total atrazine concentrations in baseflow samples from the Regional Study Area surface-water sites.

Table 7.2-6.--Water-quality characteristics of groundwater in the Regional Study area, Fall 1982

[pH, in units; CARB, carbonate; NC, noncarbonate; specific conductance in microsiemens per centimeter at 25 degrees Celsius; concentrations in milligrams per liter except pesticides, which are in micrograms per liter; fecal streptococci and fecal coliform in colonies per 100 milliliters; <, less than; ≤, less than or equal to]

Constituent	Rock type	n	Min	25%	Median 50%	75%	Max
pH	CARB	46	6.8	7.3	7.4	7.6	8.2
	NC	29	5.1	5.9	6.4	7.0	7.8
Alkalinity as $CaCO_3$	CARB	46	29	205	232	253	330
	NC	29	4.2	14	56	104	344
Acidity as $CaCO_3$	CARB	46	0	8.8	16	22	48
	NC	29	3.0	14	32	46	97
Specific conductance	CARB	46	193	586	665	816	1,020
	NC	29	31	96	190	362	928
Dissolved solids	CARB	46	106	382	421	505	792
	NC	29	28	78	158	262	728
Calcium as Ca	CARB	46	18	54	73	92	136
	NC	29	1.4	6.4	18	42	112
Magnesium as Mg	CARB	46	6.9	20	31	38	48
	NC	29	.6	2.4	4.8	9.8	50
Hardness	CARB	46	86	269	303	354	470
	NC	29	7.2	24	71	142	420
Sodium as Na	CARB	46	1.6	4.7	8.2	14	68
	NC	29	1.1	2.5	6.5	8.4	23
Potassium as K	CARB	46	.76	1.5	2.2	3.6	12
	NC	29	.46	.75	1.0	1.4	6.3
Chloride as Cl	CARB	46	3.0	13	20	35	545
	NC	29	2.0	3.0	7.0	10	50
Sulfate as SO_4	CARB	46	5.0	20	32	65	410
	NC	29	.86	5.0	15	28	345
Nitrate as N	CARB	46	.02	4.5	8.3	12	40
	NC	29	.06	1.3	3.4	6.1	10
Orthophosphorus as P	CARB	46	≤.01	≤.01	≤.01	≤.01	.09
	NC	29	≤.01	≤.01	.04	.07	.16
Streptococci, fecal	CARB	45	1	4	12	58	10,000
	NC	29	1	6	9	20	320
Coliform, fecal	CARB	43	≤1	≤1	≤1	4	900
	NC	29	≤1	≤1	≤1	≤1	36

Most of the wells located in carbonate geology are also in areas of intensive agriculture. Sources of nitrates and herbicides in ground water are infiltration of agricultural chemicals, manure, waste water from septic tanks, and atmospheric deposition. The primary factors that affect the rate of infiltration of the contaminating constituents are their solubility in water, the amount of precipitation, and the geology of the source area. Nitrate is highly soluble, and many of the herbicides applied to agricultural fields are partially soluble in water. Consequently, these constituents can be easily leached to the water table by rain or melting snow and ice. In carbonate areas, such as the upper Conestoga River basin, numerous sinkholes and solution-enlarged fractures in the rocks allow direct rapid transport of both soluble and insoluble compounds of nitrogen and herbicides into ground water.

Bacteriological results from one sampling in the fall of 1982 (table 7.2-6) showed that densities of fecal-coliform bacteria, ranging from 1 to 900 colonies per 100 ml, were found at about one-third of the water samples collected from wells in carbonate areas. Only one water sample collected from the wells in noncarbonate areas contained fecal coliform above 1 colony per 100 ml. Data from the same sampling showed that all wells contained fecal-streptococci bacteria, and densities ranged from 1 to 295 colonies per 100 ml. Water samples with the highest densities (>28 colonies per 100 ml) were from wells located in carbonate rock areas. Fecal coliform and fecal streptococci bacteria are indicators of fecal contamination from warmblooded animals and of the possible presence of enteric microbial pathogens in the water (U.S. Environmental Protection Agency, 1976). The contamination may reflect only localized influences.

Nitrate and herbicide concentrations were also generally higher in water from wells in carbonate rock than water from wells in other geologic settings. The median nitrate concentration for 46 of the carbonate wells sampled in the fall of 1982, was 8.3 mg/L, and in 29 of the noncarbonate wells was 3.4 mg/L (table 7-2.6). Forty percent of the carbonate wells exceeded the EPA drinking water criterion (U.S. Environmental Protection Agency, 1980) of 10 mg/L as N, and only 7 percent of the noncarbonate wells exceeded the criterion during the fall sampling.

Of the 43 wells sampled for nitrates and herbicides during the three samplings in 1983 and one sampling in the fall of 1982, 33 wells were in carbonate rocks and 10 were in noncarbonate rocks (fig. 7.2-4). Thirty-two of the wells were in agricultural areas, and 11 were in nonagricultural areas, primarily residential neighborhoods or small towns surrounded by agricultural fields.

The nitrate concentrations were substantially higher in the agricultural areas than in the residential areas. The maximum nitrate concentrations as nitrogen for the four sampling periods ranged from 37 to 40 mg/L in the agricultural areas and from 12 to 19 mg/L in the nonagricultural areas. Median concentrations of nitrate ranged from 8.6 to 12 mg/L and from 3.4 to 3.8 mg/L in the agricultural and nonagricultural areas, respectively. However, median concentrations of nitrate generally were three times higher in wells that penetrated carbonate rock than in wells that penetrated noncarbonate rocks. Throughout the year, more than 40 percent of the wells sampled in the carbonate and agricultural areas had dissolved-nitrate concentrations that exceeded 10 mg/L as nitrogen, the EPA drinking water criterion (fig. 7.2-4 and table 7.2-7).

Atrazine, alachlor, and metolachlor, the herbicides detected most frequently, were found almost exclusively in the agricultural, carbonate areas (fig. 7.2-5 and table 7.2-8). In the nonagricultural area, atrazine was found in only one sample at 0.2 mg/L. In the agricultural area, maximum concentrations of atrazine and metolachlor were found in the spring, and alachlor in the fall, although all were applied as pre-emergent herbicides in May and June. The percentage of wells in which atrazine was detected was about constant throughout the year (table 7.2-9). This appears to indicate that a significant amount of herbicide remains in the soils and is leached to the ground-water system after the growing season.

Table 7.2-7.--Percentage of wells in the Regional study area exceeding USEPA criterion for nitrate in drinking water (10 milligrams per liter as N)

	Agricultural in carbonate (28 wells)	Nonagricultural in carbonate (5 wells)	Agricultural in noncarbonate (4 wells)	Nonagricultural in noncarbonate (6 wells)
Fall 1982	46	40	0	0
Spring 1983	48	60	0	0
Summer 1983	75	40	25	33
Fall 1983	54	40	0	0

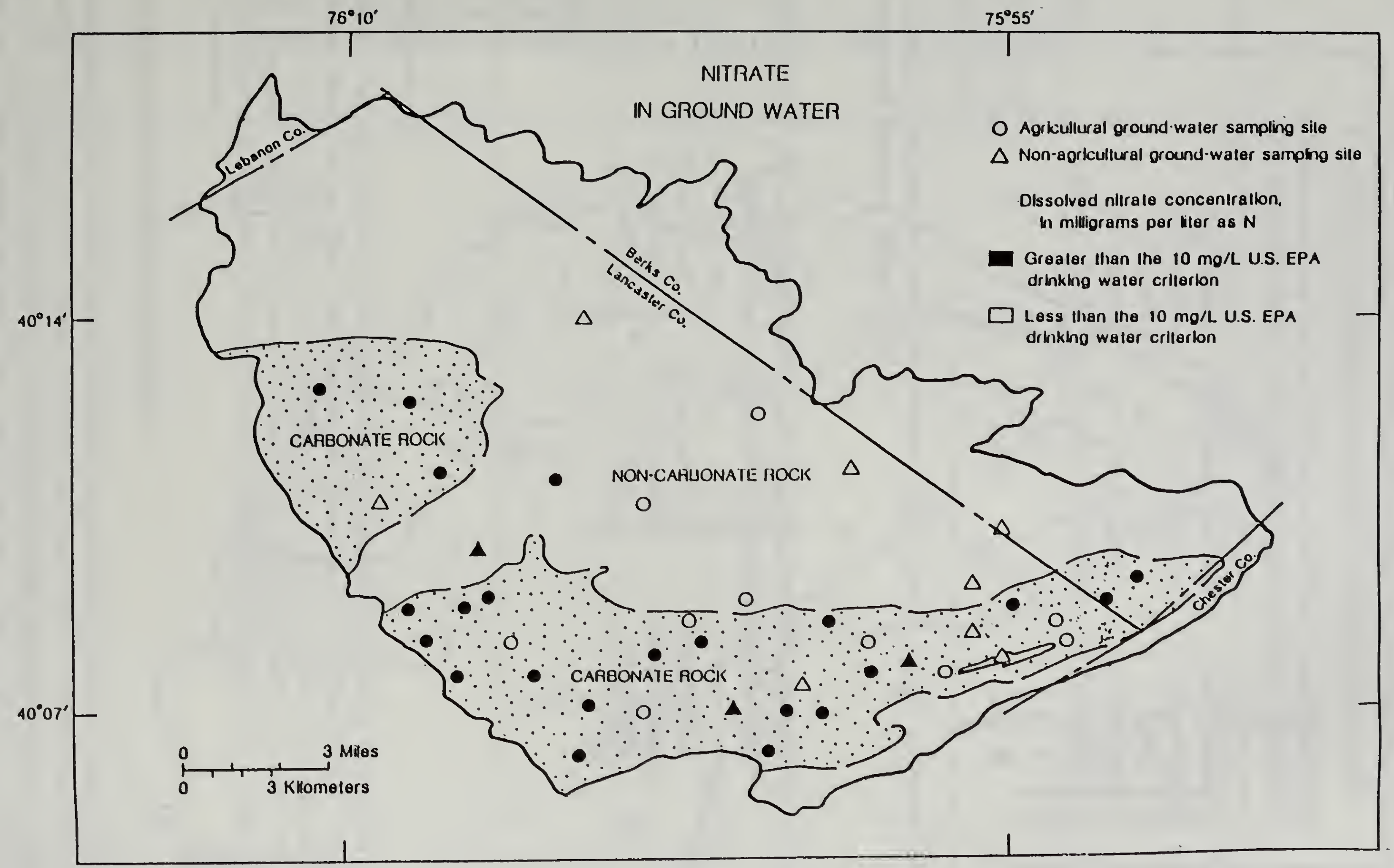


Figure 7.2-4.--Locations where ground-water sampling occured on all four sampling periods in 1982 and 1983 and associated nitrate concentration levels found in the summer 1983 samples.

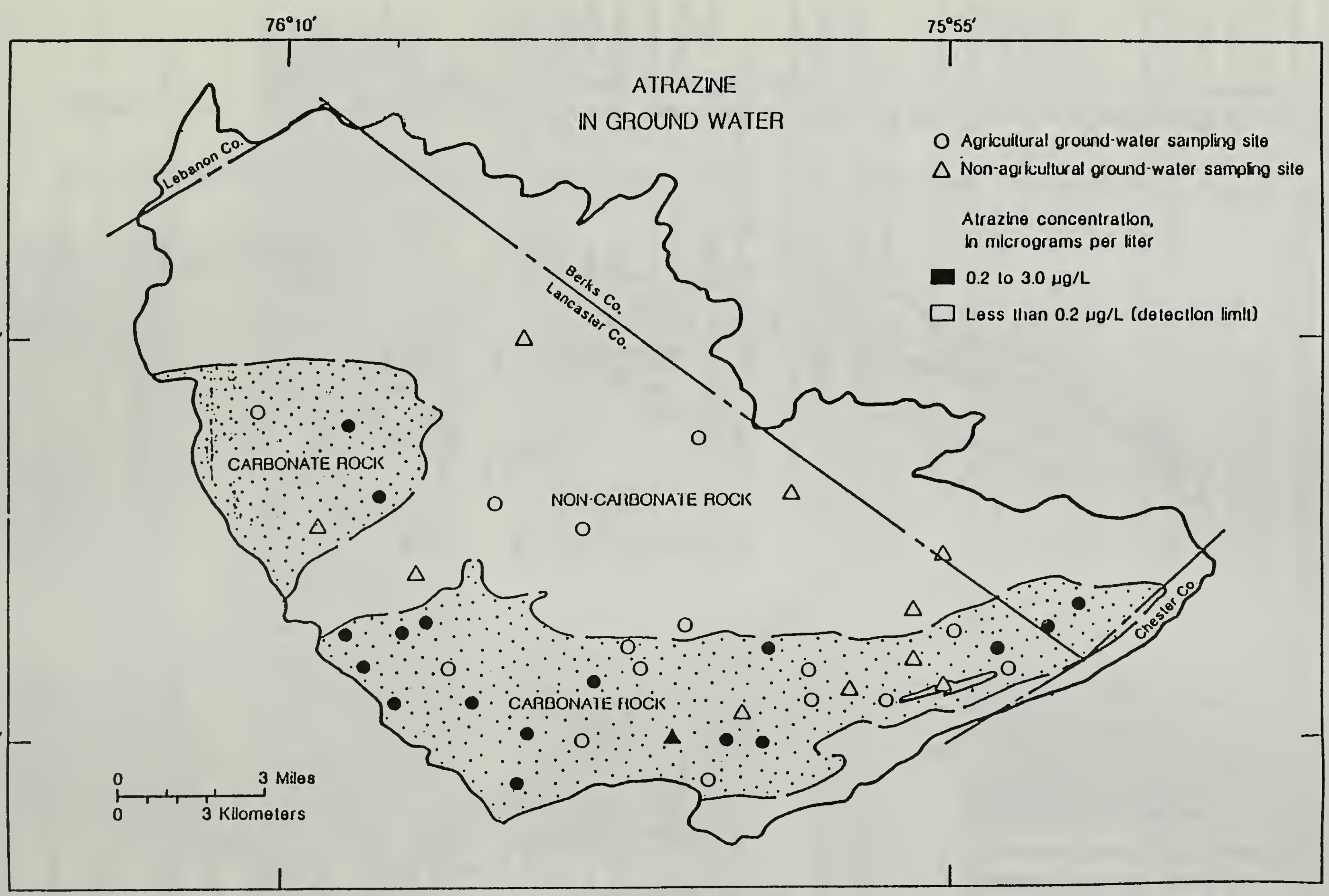


Figure 7.2-5.--Maximum atrazine concentration levels at each site for any of the three ground-water sampling periods in 1983.

Table 7.2-8.--Percentage of well samples in the Regional Study area sampled three times--spring, summer, and fall 1983--containing detectable concentrations, and the maximum concentrations of selected herbicides in agricultural and nonagricultural settings underlain by carbonate or noncarbonate rocks

[Concentrations are in micrograms per liter; Max, maximum; DL, detection limit; <, less than; ≥, greater than or equal to]

	Agricultural in carbonate (28 wells, 84 samples)		Nonagricultural in carbonate (5 wells, 15 samples)		Agricultural in noncarbonate (4 wells, 12 samples)	Nonagricultural in noncarbonate (6 wells, 18 samples)
Herbicides	Max	Percentage	Max	Percentage	Percentage	Percentage
Atrazine[1] (DL ≥ 0.2)	3.0	41	0.2	7	0	0
Alachlor[1] (DL ≥ 0.05)	3.0	12	<.05	0	0	0
Metolachlor[1] (DL ≥ 0.1)	.4	7	<.1	0	0	0

[1] The lifetime health advisory levels are: atrazine, 3 μg/L; alachlor, 2 μg/L; and metolachlor, 100 μg/L (U.S. Environmental Protection Agency, 1990)

Table 7.2-9.--Percentage of wells containing detectable concentrations of atrazine (greater than or equal to 0.2 micrograms per liter)

	Agricultural in carbonate (28 wells)	Nonagricultural in carbonate (5 wells)	Agricultural in noncarbonate (4 wells)	Nonagricultural in noncarbonate (6 wells)
Spring 1983	36	0	0	0
Summer 1983	46	0	0	0
Fall 1983	39	20	0	0

7.2.5 Regional Fish

Four sites were sampled for the fish community composition in October 1982 (table 6-4). A total of 18 species were collected at the Little Conestoga site, 20 species at the Conestoga site, 26 species at the Muddy Creek site, and 32 species at the Cocalico site (table 7.2-10). None of these fish communities appears to be adversely impacted; their diversity and numbers were likely limited by habitat and natural physio-chemical conditions. Compared to the PaDER 1976 and SRBC 1985 studies, the 1982 data shows a more diverse community.

7.2.6 Regional Benthic Macroinvertebrates

Studies assessing the benthic macroinvertebrate communities within the Conestoga River Basin were conducted in 1982, 1988, and 1989, by the Pennsylvania Department of Environmental Resources (PaDER) (tables 7.2-11 to 7.2.13). These surveys were performed using similar collection techniques, but were performed at different intensities and flow conditions. As a result, in-depth comparative quantitative treatment of the data was not attempted. The data do serve, however, as a valuable historical/baseline information source and will be utilized to form some possible qualitative interpretations of water-quality changes across the eight-year interval.

Table 7.2-10.--Fish species and counts found at four sites in the Conestoga Headwater River basin (table 6-4)

[A, abundant; C, common; P, present; R, rare]

Taxa	5	3 CR	5 MC	7 CC
	Sampling station			
CYPRINIDAE (Minnows)				
Cutlips minnow				
Exoglossum maxillingua			P	C
Satinfin shiner				
Notropis analostanus			P	
Common shiner				
Notropis cornutus	4		A	P
Swallowtail shiner				
Notropis procne	25		P	A
Rosyface shiner				
Notropis rubellus			A	R
Spotfin shiner				
Notropis spilopterus	11	A	P	P
Blacknose dace				
Rhinichthys atratulus	580	R	P	R
Bluntnose minnow				
Pimephales notatus	5	P	P	P
Longnose dace				
Rhinichthys cataractae	816	P	C	P
Creek chub				
Semotilus atromaculatus	38		P	R
River chub				
Nocomis micropogon			P	R
Goldfish				
Carassius auratus		R		
Common carp				
Cyprinus carpio	1	P		
Golden shiner				
Notemigonus crysoleucas		C		
Spottail shiner				
Notropis hudsonius	20	A		A
CATOSTOMIDAE (Suckers)				
White sucker				
Catostomus commersoni	112	C	C	A
Northernhog sucker				
Hypentelium nigricans	12	C	C	C
ICTALURIDAE (Catfishes)				
Yellow bullhead				
Ictalurus natalis		5	63	54
Brown bullhead				
Ictalurus nebulosus	37	2	1	
Margined madtom				
Noturus insignis			P	R

Table 7.2-10.--Fish species and counts found at four sites in the Conestoga Headwater River basin (table 6-4)--Continued

[A, abundant; C, common; P, present; R, rare]

Taxa	Sampling station			
	5	3 CR	5 MC	7 CC
CYPRINODONTIDAE (Killifish)				
Banded killifish				
Fundulus diaphanus	1			
CENTRARCHIDAE (Sunfishes)				
Rock bass				
Ambloplites rupestris	1	126	78	425
Redbreast sunfish				
Lepomis auritus	69	37	156	319
Green sunfish				
Lepomis cyanellus	42	617	175	86
Pumpkinseed sunfish				
Lepomis gibbosus	1	141	32	1
Bluegill				
Lepomis macrochirus		9	27	
Smallmouth bass				
Micropterus dolomieui		33	281	139
Largemouth bass				
Micropterus salmoides		7	11	
Black crappie				
Pomoxis nigromaculatus			1	
Hybrid sunfish				
Lepomis spp				1
PERCIDAE (Perches)				
Tesselated darter				
Etheostoma olmstedi	99	P	C	A
Shield darter				
Percina peltata			R	

Table 7.2-11.--Benthic macroinvertebrate quantitative[1] results

Taxa	Station 1CR 4/82	Station 1CR 5/89	Station 2CR 4/82	Station 2CR 5/89	Station 3CR 4/82	Station 3CR 5/89	Station 4MC 4/82	Station 4MC 5/89	Station 5MC 4/82	Station 5MC 5/89	Station 6CC 4/82	Station 6CC 5/89	Station 7CC 4/82	Station 7CC 5/89
Ephemeroptera - mayflies														
Baetidae														
Baetis	*	5	*	14	*	6	*	1	*	25	*	27	*	18
Pseudocloeon	*	*	*	*	*	*	1	*	*	*	*	26	*	*
Caenidae														
Caenis	*	*	*	*	*	2	*	*	*	1	*	*	1	1
Ephemerellidae														
Ephemerella	*	*	*	141	*	*	*	8	*	1	*	185	*	61
Serratella	*	*	*	*	*	*	1	*	2	*	12	6	*	*
Heptageniidae	*	*	*	*	1	*	*	*	*	*	1	*	*	*
Cinygmula	*	*	*	4	*	*	*	*	*	*	*	*	*	*
Epeorus	*	*	*	5	*	*	*	*	*	*	*	5	*	*
Stenacron	*	*	*	1	*	*	*	*	*	*	*	*	*	*
Stenonema	*	*	2	31	11	39	*	2	6	20	3	4	7	13
Leptophlebiidae														
Paraleptophlebia	*	*	*	9	*	*	*	1	*	*	*	*	*	*
Oligoneuriidae														
Isonychia	*	*	*	*	*	2	1	*	2	*	*	*	*	*
Plecoptera - stoneflies														
Chloroperlidae														
Haploperla	*	*	*	1	*	*	*	*	*	*	*	*	*	*
Leuctridae														
Leuctra	*	*	*	1	*	*	*	*	*	*	*	*	*	*
Nemouridae														
Amphinemura	*	*	*	4	*	*	1	1	*	*	*	*	*	*
Perlidae														
Eccoptura xanthenes	*	*	*	*	*	*	*	*	*	*	*	1	*	*
Perlodidae														
Isoperla holochlora	*	*	*	24	*	*	*	1	*	*	*	1	*	*

Table 7.2-11.--Benthic macroinvertebrate quantitative[1] results--Continued

Taxa	Station 1CR		Station 2CR		Station 3CR		Station 4MC		Station 5MC		Station 6CC		Station 7CC	
	4/82	5/89	4/82	5/89	4/82	5/89	4/82	5/89	4/82	5/89	4/82	5/89	4/82	5/89
Trichoptera - caddisflies														
Hydropsychidae	*	11	*	*	*	*	*	*	*	*	*	37	*	19
Cheumatopsyche	2	46	14	19	14	3	15	29	16	10	9	48	144	26
Diplectrona	*	*	*	12	*	*	*	*	*	*	*	*	*	*
Hydropsyche (Ceratopsyche)	*	29	4	25	3	10	*	13	*	3	*	25	24	18
Hydropsyche (Hydropsyche)	6	298	4	31	*	5	23	51	8	12	3	72	17	211
Hydroptilidae														
Hydroptila	*	2	*	1	*	*	*	*	*	*	*	*	*	*
Leucotrichia	*	*	*	*	*	*	*	*	7	*	7	13	*	4
Lepidostomatidae														
Lepidostoma	*	*	*	5	*	*	*	*	*	*	*	*	*	*
Limnephilidae														
Goera	*	*	*	*	*	*	*	*	*	*	*	1	*	*
Philopotamidae														
Chimarra	*	10	*	*	*	*	*	3	1	1	1	3	56	81
Dolophilodes	*	*	*	*	*	*	*	*	*	*	*	3	*	*
Polycentropodidae														
Cyrnellus	*	*	*	*	*	*	*	*	*	*	*	2	*	*
Psychomyiidae														
Psychomyia	*	*	1	*	*	*	*	1	*	*	1	32	1	1
Rhyacophilidae														
Rhyacophila	*	*	*	*	*	*	*	*	1	*	4	*	*	*
Rhyacophila carolina	*	*	*	1	*	*	*	*	*	*	*	*	*	*
Rhyacophila fuscula	*	*	*	*	*	*	*	*	*	*	*	2	*	*
Uenoidae														
Neophylax	*	1	*	4	*	*	*	2	*	*	4	7	*	*

Table 7.2-11.--Benthic macroinvertebrate quantitative[1] results--Continued

Taxa	Station 1CR 4/82	Station 1CR 5/89	Station 2CR 4/82	Station 2CR 5/89	Station 3CR 4/82	Station 3CR 5/89	Station 4MC 4/82	Station 4MC 5/89	Station 5MC 4/82	Station 5MC 5/89	Station 6CC 4/82	Station 6CC 5/89	Station 7CC 4/82	Station 7CC 5/89
Diptera - true flies														
Empididae	*	*	*	*	*	1	*	2	*	*	2	*	1	11
Chelifera	*	*	*	1	*	*	*	*	*	*	*	*	*	*
Hemerodromia	*	8	*	5	2	2	1	2	1	*	2	38	1	2
Psychodidae														
Pericoma	*	*	*	9	*	*	*	*	*	*	*	*	*	*
Simuliidae	*	*	*	*	1	*	*	*	*	*	1	*	4	*
Prosimulium	*	*	1	*	5	*	*	*	*	*	*	*	28	*
Simulium	1	33	2	26	1	2	4	185	*	7	47	6	8	11
Stratiomyiidae	*	*	*	*	*	*	*	*	*	*	1	*	*	*
Tabanidae	*	*	*	*	*	*	*	*	1	*	*	*	*	*
Tipulidae														
Antocha	*	23	4	*	1	1	9	2	*	*	10	90	10	5
Erioptera	*	*	*	*	*	*	*	1	*	*	*	*	*	*
Hexatoma	*	3	*	*	*	*	*	1	*	2	7	18	2	2
Molophilus	*	*	*	1	*	*	*	*	*	*	*	*	*	*
Pilaria	*	*	*	*	1	*	*	*	*	*	*	*	*	*
Tipula	*	*	*	*	*	*	*	*	*	*	*	*	1	*
Chironomidae	71	313	91	471	310	470	*	156	25	55	8	311	41	203
Chironominae	*	*	10	*	8	*	53	*	29	*	31	*	18	*
Tanypodinae	*	*	*	*	1	*	*	*	2	*	*	*	4	*
Diamesinae	*	*	1	*	*	*	*	*	*	*	*	*	11	*
Orthocladiinae	*	*	40	*	88	*	65	*	47	*	8	*	55	*

Table 7.2-11.--Benthic macroinvertebrate quantitative[1] results--Continued

Taxa	Station 1CR		Station 2CR		Station 3CR		Station 4MC		Station 5MC		Station 6CC		Station 7CC	
	4/82	5/89	4/82	5/89	4/82	5/89	4/82	5/89	4/82	5/89	4/82	5/89	4/82	5/89
Other Insect Taxa														
Megaloptera - dobson-, alder-, fishflies														
Corydalidae														
Corydalus	*	*	*	*	*	*	*	1	*	*	*	*	*	1
Odonata - dragon-damselflies														
Coenagrionidae														
Amphiagrion	*	*	*	*	*	*	*	1	*	*	*	*	*	*
Argia	*	1	*	*	1	*	1	*	*	*	*	*	*	*
Coleoptera - aquatic beetles														
Elmidae														
Ancyronyx	*	*	*	*	*	*	*	*	*	*	*	*	1	*
Dubiraphia	*	*	*	*	1	*	*	*	*	*	*	*	*	*
Gonielmis	*	*	*	*	1	*	*	*	*	*	*	*	*	*
Macronychus	1	*	1	*	1	*	*	*	*	*	*	1	1	1
Optioservus	*	*	*	1	*	*	*	3	*	*	*	1	*	1
Oulimnius	*	1	*	1	*	*	*	*	*	*	*	1	*	*
Stenelmis	3	108	48	72	19	37	*	112	14	18	40	72	100	171
Hydrophilidae	*	*	1	*	*	2	*	*	*	*	*	*	*	*
Psephenidae														
Psephenus	*	*	*	*	*	*	*	3	*	4	7	11	3	13
Eubriidae														
Ectopria	*	*	*	4	*	*	*	*	*	*	*	*	*	*
Lepidoptera														
Pyralidae														
Petrophila	*	*	*	*	*	*	*	*	*	1	*	*	*	7

Table 7.2-11.--Benthic macroinvertebrate quantitative[1] results--Continued

Taxa	Station 1CR 4/82	Station 1CR 5/89	Station 2CR 4/82	Station 2CR 5/89	Station 3CR 4/82	Station 3CR 5/89	Station 4MC 4/82	Station 4MC 5/89	Station 5MC 4/82	Station 5MC 5/89	Station 6CC 4/82	Station 6CC 5/89	Station 7CC 4/82	Station 7CC 5/89
Non-Insect Taxa														
Turbellaria - flatworms	*	*	6	*	*	*	3	*	1	*	*	*	3	*
Cura	*	*	*	1	*	*	*	*	1	*	*	*	*	*
Dugesia	*	*	6	*	*	*	*	*	*	*	*	*	*	*
Nematoda - roundworms	2	*	*	*	*	*	*	*	*	*	2	*	2	*
Oligochaeta	*	*	*	50	*	2	*	4	1	*	*	*	*	1
Oligochaeta - tubificid type	*	17	20	*	46	8	22	16	1	5	*	7	24	6
Amphipoda - scuds														
Crangonyctidae														
Crangonyx	*	*	*	*	*	*	*	*	*	*	*	*	1	*
Decapoda - crayfish														
Cambaridae	1	*	*	1	*	*	*	*	*	*	*	*	*	*
Orconectes	*	*	*	*	*	1	*	*	*	*	*	*	*	*
Gastropoda - univalves, snails														
Ancylidae														
Ferrissia	*	*	*	*	1	*	14	*	1	*	*	*	*	*
Pleuroceridae	*	*	*	*	*	12	*	*	*	*	*	*	*	*
Pelecypoda - clams, mussels														
Sphaeriidae	*	*	*	*	*	*	*	*	*	*	1	*	4	*
Total number taxa[2]	8	16	16	32	18	16	15	24	27	15	20	30	26	22
Individuals	87	909	256	976	517	605	214	602	167	165	212	1,056	573	888

[1]Combined totals of 3 surber sq. ft. samples.

[2]Total number taxa does not include "family" taxon level where genera in that family have already been identified.

*Not found in Surber samples.

Table 7.2-12.--Benthic macroinvertebrate qualititative[1] results

Taxa	Station 1CR			Station 2CR			Station 3CR			Station 4MC			Station 5MC			Station 6CC			Station 7CC		
	4/82	10/88	5/89	4/82	10/88	5/89	4/82	10/88	5/89	4/82	10/88	5/89	4/82	10/88	5/89	4/82	10/88	5/89	4/82	10/88	5/89
Ephemeroptera - mayflies																					
Baetidae																					
Baetis	*	*	X	*	P	X	*	*	*	*	C/A	*	R	P	X	*	C	*	*	P	*
Pseudocloeon	*	*	*	*	*	*	*	*	*	(S)	*	*	*	*	*	*	*	(S)	*	*	*
Caenidae																					
Caenis	*	*	*	*	*	*	*	*	X	*	*	*	*	*	*	*	*	*	R	*	*
Ephemerellidae																					
Ephemerella	*	*	*	*	*	X	R	*	*	C	R	X	*	R	X	C	*	X	R	R	X
Eurylophella	*	*	*	*	*	*	*	*	*	P	*	*	*	*	*	R	*	*	*	*	*
Serratella	*	*	*	*	*	*	*	*	*	(S)	*	*	(S)	*	*	(S)	*	*	*	*	*
Ephemeridae																					
Ephemera	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	R	*	*
Heptageniidae																					
Cinygmula	*	*	*	*	*	(S)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Epeorus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	R	*	*	*	*	*
Leucrocuta	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	X
Stenacron	*	*	*	*	*	*	*	P	*	C	*	*	*	P	*	*	*	*	R	*	*
Stenonema	*	*	*	P	P	X	P	P	X	P	P	X	C	C	X	A	P	X	C	P/C	X
Leptophlebiidae																					
Paraleptophlebia	*	*	*	*	*	(S)	*	*	*	*	(S)	*	*	*	*	*	*	*	*	*	*
Oligoneuriidae																					
Isonychia	*	*	*	R	P	X	*	C	X	(S)	R	X	C	P/C	X	R	R	*	C	C	X
Plecoptera - stoneflies																					
Leuctridae																					
Leuctra	*	*	*	*	(S)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Paraleuctra	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	R	*	*
Nemouridae																					
Amphinemura	*	*	*	*	*	*	*	*	*	(S)	*	*	*	*	*	*	*	*	*	*	*
Ostrocerca	R	*	*	*	*	*	*	*	*	P	*	*	*	*	*	*	*	*	*	*	*
Perlidae																					
Acroneuria	*	R	*	*	*	*	*	*	*	R	*	*	*	*	*	*	*	*	*	*	*
Eccoptura xanthenes	*	*	*	*	*	*	*	*	*	R	*	*	*	*	*	*	P	(S)	*	*	*
Perlodidae																					
Isoperla	*	*	*	*	*	*	*	*	*	*	*	X	*	*	*	*	*	*	*	*	*

Table 7.2-12.--Benthic macroinvertebrate qualititative[1] results--*Continued*

Taxa	Station 1CR			Station 2CR			Station 3CR			Station 4MC			Station 5MC			Station 6CC			Station 7CC		
	4/82	10/88	5/89	4/82	10/88	5/89	4/82	10/88	5/89	4/82	10/88	5/89	4/82	10/88	5/89	4/82	10/88	5/89	4/82	10/88	5/89
Trichoptera - caddisflies																					
Hydropsychidae																					
Cheumatopsyche	P	*	X	C	C	X	C	C	(S)	C	C	(S)	C	C	X	C	C	(S)	A	A	X
Diplectrona	*	*	*	*	*	(S)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Hydropsyche																					
(Ceratopsyche)	P	*	X	P	A	X	P	*	X	P	*	X	*	*	(S)	P	*	X	P	*	X
Hydropsyche																					
(Hydropsyche)	P	A	X	(S)	C	X	P	C	X	P	C	X	P	C	*	R	C	X	P	A	X
Hydroptilidae																					
Hydroptila	*	*	(S)	*	*	(S)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Leucotrichia	*	*	*	*	*	*	*	*	*	A	*	*	P	*	*	A	*	(S)	*	*	(S)
Lepidostomatidae																					
Lepidostoma	*	*	*	*	*	(S)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Limnephilidae																					
Goera	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	(S)	*	*	*
Philopotamidae																					
Chimarra	*	P	X	*	R	X	*	*	*	*	C	X	R	P	*	R	P	(S)	A	C	X
Dolophilodes	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	X	*	*	*
Polycentropodidae																					
Cyrnellus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	(S)	*	*	*
Psychomyiidae																					
Psychomyia	*	*	*	(S)	*	*	*	*	*	*	*	(S)	*	*	*	(S)	R	(S)	*	*	*
Rhyacophilidae																					
Rhyacophila	*	*	*	*	*	*	*	*	*	*	*	*	(S)	*	*	(S)	*	*	*	*	*
Rhyacophila fuscula	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	X	*	*	*
Uenoidae																					
Neophylax	*	*	(S)	*	*	(S)	*	*	*	*	*	(S)	*	*	*	C	*	(S)	*	*	*

Table 7.2-12.--Benthic macroinvertebrate qualititative[1] results--Continued

Taxa	Station 1CR 4/82	Station 1CR 10/88	Station 1CR 5/89	Station 2CR 4/82	Station 2CR 10/88	Station 2CR 5/89	Station 3CR 4/82	Station 3CR 10/88	Station 3CR 5/89	Station 4MC 4/82	Station 4MC 10/88	Station 4MC 5/89	Station 5MC 4/82	Station 5MC 10/88	Station 5MC 5/89	Station 6CC 4/82	Station 6CC 10/88	Station 6CC 5/89	Station 7CC 4/82	Station 7CC 10/88	Station 7CC 5/89
Diptera - true flies	*	P	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Athericidae																					
Atherix	*	P	*	*	*	*	*	*	*	*	R	*	R	R	*	*	*	*	*	*	*
Empididae	*	*	X	*	*	*	*	*	(S)	*	*	(S)	*	*	*	(S)	*	*	(S)	*	(S)
Chelifera	*	*	*	*	*	(S)	R	*	*	*	*	*	*	*	*	*	*	*	R	*	*
Clinocera	*	*	*	*	*	*	*	*	*	R	*	*	*	*	*	*	*	*	*	*	*
Hemerodromia	R	*	(S)	R	*	(S)	(S)	*	(S)	(S)	*	(S)	(S)	*	*	R	*	(S)	R	*	(S)
Psychodidae																					
Pericoma	*	*	*	*	*	(S)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Simuliidae	*	*	*	*	*	*	*	*	*	*	R	*	R	*	(S)	*	P	*	(S)	*	*
Prosimulium	C	*	*	(S)	*	*	(S)	*	*	P	*	*	*	*	*	R	*	*	C	*	*
Simulium	C	R	X	R	*	X	R	*	(S)	P	*	X	*	*	X	C	*	(S)	P	*	(S)
Stratiomyiidae	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	(S)	*	*	*	*	*
Tabanidae	*	*	*	*	*	*	R	*	*	R	*	X	(S)	*	*	*	*	*	*	*	*
Tipulidae																					
Antocha	*	*	(S)	(S)	*	X	(S)	*	(S)	(S)	*	(S)	*	*	*	(S)	*	(S)	(S)	*	(S)
Erioptera	*	*	*	*	*	*	*	*	*	*	*	(S)	*	*	*	*	*	*	*	*	*
Hexatoma	*	R	X	*	*	*	*	*	*	C	*	X	*	*	X	P	C	X	P	P	X
Molophilus	*	*	*	*	*	(S)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Pilaria	*	*	*	*	*	*	(S)	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tipula	R	*	*	*	R	*	R	*	*	*	R	*	*	R	*	P	*	*	(S)	*	*
Chironomidae	(S)	C	X	(S)	P	X	(S)	P	X	(S)	P	X	(S)	P	X	(S)	C	X	(S)	P	X
Chironominae	*	*	*	C	*	*	P	*	*	P	*	*	C	*	*	C	*	*	P	*	*
Tanypodinae	C	*	*	R	*	*	P	*	*	R	*	*	R	*	*	R	*	*	P	*	*
Diamesinae	C	*	*	*	*	*	(S)	*	*	A	*	*	*	*	*	R	*	*	P	*	*
Orthocladiinae	C	*	*	A	*	*	C	*	*	A	*	*	C	*	*	P	*	*	C	*	*

Table 7.2-12.--Benthic macroinvertebrate qualititative[1] results--*Continued*

Taxa	Station 1CR			Station 2CR			Station 3CR			Station 4MC			Station 5MC			Station 6CC			Station 7CC		
	4/82	10/88	5/89	4/82	10/88	5/89	4/82	10/88	5/89	4/82	10/88	5/89	4/82	10/88	5/89	4/82	10/88	5/89	4/82	10/88	5/89
Other Insect Taxa																					
Megaloptera - dobson-, alder-, fishflies																					
Corydalidae																					
Corydalus	*	*	*	R	*	*	*	R	*	R	R	(S)	P	C	X	*	*	*	R	P/C	*
Nigronia	R	R	*	*	*	*	*	*	*	*	*	*	*	*	*	R	P	*	*	*	*
Sialidae																					
Sialis	*	*	*	*	*	*	*	R	*	*	*	*	*	R	*	*	*	*	*	R	*
Odonata - dragon-damselflies																					
Aeshnidae																					
Boyeria	*	*	*	*	*	*	*	*	*	R	*	*	*	*	*	*	R	*	*	*	*
Coenagrionidae																					
Amphiagrion	*	*	*	*	*	*	*	*	*	*	*	(S)	*	*	*	*	*	*	*	*	*
Argia	*	R	(S)	R	*	*	(S)	R	X	A	*	X	R	P	X	R	*	*	R	R	X
Coleoptera - aquatic beetles																					
Dryopidae																					
Helichus	*	*	*	*	*	*	*	*	*	R	*	*	*	*	*	*	*	*	*	*	*
Elmidae																					
Ancyronyx	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	(S)	*	*
Dubiraphia	*	*	*	*	*	*	(S)	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Gonielmis	*	*	*	*	*	*	(S)	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Macronychus	(S)	*	*	(S)	*	*	(S)	*	*	*	*	*	*	*	*	*	*	(S)	R	*	(S)
Optioservus	*	*	*	*	*	(S)	*	*	*	*	*	(S)	*	*	*	R	*	(S)	*	*	(S)
Oulimnius	*	*	(S)	*	*	(S)	*	*	*	*	*	*	*	*	(S)	*	*	*	*	*	*
Stenelmis	R	P	X	VA	C	X	VA	P	X	C	P	X	A	P	X	A	P/C	X	A	C	X
Hydrophilidae	*	*	*	(S)	*	*	*	*	(S)	*	*	*	*	*	*	*	*	*	R	*	*
Psephenidae																					
Psephenus	*	*	*	*	*	*	*	*	X	C	P	X	C	P	X	C	P	X	(S)	P	X
Eubriidae																					
Ectopria	*	*	*	*	*	(S)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Lepidoptera																					
Pyralidae																					
Petrophila	*	*	*	*	*	*	*	*	*	*	*	*	*	*	(S)	*	*	*	*	*	(S)

Table 7.2-12.--Benthic macroinvertebrate qualititative[1] results--Continued

Taxa	Station 1CR 4/82	Station 1CR 10/88	Station 1CR 5/89	Station 2CR 4/82	Station 2CR 10/88	Station 2CR 5/89	Station 3CR 4/82	Station 3CR 10/88	Station 3CR 5/89	Station 4MC 4/82	Station 4MC 10/88	Station 4MC 5/89	Station 5MC 4/82	Station 5MC 10/88	Station 5MC 5/89	Station 6CC 4/82	Station 6CC 10/88	Station 6CC 5/89	Station 7CC 4/82	Station 7CC 10/88	Station 7CC 5/89
Non-Insect Taxa																					
Turbellaria - flatworms	R	*	*	R	P	*	R	*	*	P	P	X	R	*	*	R	*	*	(S)	P	*
Nematoda - roundworms	(S)	*	*	*	*	*	*	*	*	*	*	*	*	*	*	(S)	*	*	(S)	*	*
Oligochaeta	R	*	*	R	*	*	C	P	*	R	R	*	R	*	*	R	*	*	R	*	*
Oligochaeta - lumbricid type	*	*	*	*	R	*	*	*	*	*	*	*	*	R	*	*	*	*	*	P	*
Oligochaeta - tubificid type	*	*	(S)	*	*	X	*	*	(S)	*	*	(S)	*	*	X	*	*	(S)	*	*	X
Hirudinea - leeches	*	*	*	*	*	*	*	*	*	R	P	*	*	*	*	*	*	*	*	*	*
Isopoda - aquatic sowbugs																					
Asellidae																					
Asellus	*	*	*	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*	R	*	*
Amphipoda - scuds	*	*	*	*	R	*	*	P	*	*	P	*	*	*	*	*	*	*	*	*	*
Gammaridae																					
Gammarus	*	*	*	*	*	X	*	*	*	*	*	*	R	*	*	*	*	*	*	*	*
Crangonyctidae																					
Crangonyx	*	*	*	*	*	*	*	*	*	P	*	*	*	*	*	*	*	*	(S)	*	X
Hyalellidae																					
Hyalella azteca	*	*	*	R	*	*	R	*	*	*	*	*	*	*	*	R	*	*	R	*	*
Decapoda - crayfish																					
Cambaridae	C	*	*	*	*	*	C	*	X	*	P	*	*	*	X	C	*	*	*	*	*
Cambarus	*	P	*	*	*	*	*	*	*	*	*	*	*	R	*	*	P	*	*	*	*
Orconectes	*	*	*	R	*	*	*	P	*	C	*	*	*	*	*	*	*	*	P	*	*
Gastropoda - univalves, snails																					
Ancylidae																					
Ferrissia	*	*	*	R	*	*	(S)	R	*	R	*	*	(S)	*	*	*	*	*	R	*	*
Hydrobiidae	*	*	*	*	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Physidae																					
Physella n.r.	*	*	X	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Pleuroceridae	*	*	*	*	*	*	*	P/C	(S)	*	*	*	*	*	*	*	*	*	*	*	*
Lymnaeidae	*	*	*	R	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Pelecypoda - clams, mussels																					
Sphaeriidae	*	*	*	*	R	*	P	*	*	*	*	*	P	*	X	R	*	*	C	R	*
Total number taxa[2]	16	12	10	19	15	14	18	15	10	32	19	15	20	18	15	30	16	10	31	16	15
Individuals	(19)		(17)	(26)	(16)	(27)	(29)		(18)	(39)	(20)	(26)	(26)		(19)	(38)		(25)	(41)		(23)

[1]Relative abundances: VA, very abundant; C, common; R, rare; A, abundant; P, X, present; (S), found in concurrent surBer sample but not in kick screen.
[2]Total number taxa: (#) is combined occurrence of both kick and surber samples.
*Not found in Surber samples.

Table 7.2-13.--Water chemistry data collected when benthic macroinvertebrate sampling was conducted

[concentrations, in milligrams per liter except as noted; °C, degrees Celsius; MPN/100 ml, most probable number per 100 milliliters]

	Station 1CR			Station 2CR			Station 3CR			Station 4MC		
	4/14/82	10/25/88	5/31/89	4/14/82	10/25/88	5/31/89	4/14/82	10/25/88	5/31/89	4/14/82	10/26/88	5/30/89
Field analyses												
Temperature (°C)	12.5	9.5	20.3	10.0	11.8	19.4	9.5	9.0	19.5	12.5	7.5	--
Dissolved oxygen	13.3	10.4	9.5	16.0	11.9	10.8	11.8	10.6	10.0	13.3	11.8	--
Specific conductance (micromhos/cm)	--	275	395	--	285	350	--	310	420	--	161	--
pH	8.1	6.5	7.3	8.6	8.4	8.0	8.2	7.6	7.8	8.1	7.6	--
Laboratory analyses												
BOD (5-day)	.6	2.5	.4	1.2	2.0	.4	.8	1.5	.4	.6	1.6	<0.4
pH	6.6	7.3	8.1	8.5	8.2	7.5	8.0	7.9	7.7	6.6	7.0	7.0
Alkalinity	40	60	66	128	124	126	146	144	158	40	72	46
Total suspended solids	--	346	368	--	288	308	--	318	386	--	156	122
Volatile suspended solids	2	16	6	2	16	20	22	20	28	2	<2	<2
Total NH_3-N	.2	.05	.04	.2	.05	.04	.21	.04	.06	.2	.02	.05
Total NO_2-N	.016	.01	.008	.036	.02	.030	.038	.026	.036	.016	.008	.014
Total NO_3-N	1.28	.79	1.13	4.36	5.04	6.26	5.46	5.47	8.43	1.28	1.93	2.10
Total NH_3 + organic-N	--	.32	.26	--	.49	.36	--	.54	.21	--	<.2	.26
Total phosphorus	.13	.10	.05	.12	.16	.08	.12	.18	.11	.13	.07	.12
Chloride	15	12	11	27	18	18	28	46	18	15	10	7
Total coliform (MPN/100 ml)	--	--	450	--	--	5,900	--	--	3,400	--	--	2,800
Fecal coliform (MPN/100 ml)	--	--	60	--	--	5,200	--	--	2,500	--	--	1,400

Table 7.2-13.--Water chemistry data collected when benthic macroinvertebrate sampling was conducted--Continued

[concentrations, in milligrams per liter except as noted; °C, degrees Celsius; MPN/100 ml, most probable number per 100 milliliters]

	Station 5MC			Station 6CC			Station 7CC		
	4/14/82	10/26/88	5/30/89	4/14/82	10/26/88	5/30/89	4/14/82	10/26/88	5/30/89
Field analyses									
Temperature (°C)	10	7.9	18.1	12.5	9.0	16.5	10.0	8.0	18.7
Dissolved oxygen	16	7.6	8.8	13.3	11.6	11.0	16.0	11.2	12.8
Specific conductance (micromhos/cm)	--	219	190	--	91	90	--	190	195
pH	8.6	7.6	6.9	8.1	7.8	7.5	8.6	7.7	7.0
Laboratory analyses									
BOD (5-day)	1.2	2.0	<.4	.6	1.2	.4	1.2	1.5	.4
pH	8.5	7.0	6.7	6.6	6.8	6.5	8.5	7.1	6.9
Alkalinity	128	74	50	40	40	30	128	80	60
Total suspended solids	--	246	158	--	102	74	--	190	156
Volatile suspended solids	2	<2	10	2	<2	<2	2	<2	<2
Total NH_3-N	.2	1.21	.07	.2	.02	.08	.2	.02	.04
Total NO_2-N	.036	.044	.024	.016	.006	.020	.036	.01	.018
Total NO_3-N	4.36	2.82	4.58	1.28	1.09	1.37	4.36	2.85	4.58
Total NH_3 + organic-N	--	1.44	.34	--	.20	.31	--	.30	.26
Total phosphorus	.12	.19	.10	.13	.04	.08	.12	.11	.07
Chloride	27	31	14	15	6	4	27	16	11
Total coliform (MPN/100 ml)	--	--	2,500	--	--	11,000	--	--	3,200
Fecal coliform (MPN/100 ml)	--	--	1,100	--	--	2,500	--	--	2,100

The 1982 and 1989 surveys were conducted in the springtime, so they were more comparable than the survey conducted in October 1988. Two additional surveys were done in the Conestoga Basin; one in 1976 by the PaDER (E. Brezina, 1980) and the other in 1985 by the Susquehanna River Basin Commission (SRBC) (C. McMorran, 1986).

All sampling sites were similar in their physical characteristics--shallow riffles (less than 1.0 ft), width (less than 65 ft), and of a rubble-gravel-sand substrate. Land use was principally agricultural. Sampling locations and descriptions are given in table 6-5 and figure 6-2. Sampling protocol are described in Section 6.7.6.6.

Station 1CR was located upstream of Morgan Trailer Body on the Conestoga River, Caernarvan Township, Berks County. The benthic macroinvertebrate community showed no significant changes in the total number of taxa between 1982 and 1989, 19 and 17 total taxa, respectively (tables 7.2-11 - 7.2-12), nor in the composition of dominant taxa - the hydropsychid caddisflies, chironomids, black flies, and the elmid beetle *Stenelmis*. Twelve total taxa were collected in October 1988. No differences in community composition were noted from the other collections. Overall, station 1CR was less diverse than the other Conestoga River stations.

Station 2CR was located on the Conestoga River in East Earl Township, Lancaster County, about 60 yards upstream of Iron Bridge Road and about 12.9 mi downstream of 1CR. The macroinvertebrate community here was similar to that at 1CR in that the same dominant taxa occurred. The total number of taxa was 26 in 1982 and 27 in 1989. However, during the 1989 sampling eleven taxa of mayflies and stoneflies were collected versus only one in the 1982 quantitative samples. Sixteen total taxa were collected in October 1988.

Station 3CR was located on the Conestoga River in East Earl Township, Lancaster County, just downstream of the USGS gage and about 12.4 mi downstream of 2CR. Total taxa collected in 1982 was 29 versus 18 in 1989. Although the dominant groups did not change - hydropsychids, black flies, elmid beetles, and midges - the number of taxa was greater in the 1982 sample. Fifteen total taxa were collected in October 1988 including hellgrammites and sialids which were absent in the other collections.

Station 4MC was located on Muddy Creek in Brecknock Township, Lancaster County, upstream from Bowmansville, adjacent to the trailer park. No significant differences in dominant taxa were detected between the 1982 and 1989 collections. A total of 39 taxa in 1982 and 26 taxa in 1989 were collected. The October 1988 collection yielded 20 total taxa differing from the other collections in the presence of the mayfly *Baetis*.

Station 5MC was located on Muddy Creek at Frysville, East Cocalico Township, Lancaster County and about 9.9 mi downstream of 4MC. As at the other basin sites the hydropsychid caddisflies, midges, and elmid beetles dominated. Twenty-six total taxa were collected in 1982 versus 19 in 1989. The difference was mostly between the number of midge and elmid beetle taxa. Eighteen total taxa were collected in October 1988. Station 4MC was the most diverse site on Muddy Creek, but no stoneflies were collected at 5MC.

Station 6CC was located on Cocalico Creek in West Cocalico Township, Lancaster County, immediately upstream from Shenks Mill Road. Thirty-eight taxa were collected in 1982 versus 25 in 1989. The major difference between the two collections was the increased diversity among the caddisflies in the 1989 sample. Sixteen total taxa were collected in October 1988 differing from the other two collections by the presence of baetid mayflies.

Station 7CC was located on Cocalico Creek in East Cocalico Township, Lancaster County, off Route 272 above Ephrata and about 12.4 mi downstream of 6CC. Forty-one total taxa were collected at station 7CC in 1982 versus 23 in 1989. The communities were similar between the samples with taxa number differences due to increased midge diversity and some additional dipteran and crustacean taxa collected. In October 1988 sixteen total taxa were collected. Again, the baetid mayflies appeared in the samples from station 7CC, probably due to the time of the year.

Interestingly, a comparison of the 1982, 1988, and 1989 data collected for the Conestoga project to the 1976 PaDER and 1985 SRBC data shows little change in the dominate taxa in the Conestoga River, and Muddy, Cocalico, and Little Conestoga Creeks. The midges, elmids, hydropsychid caddisflies, and black

flies still remain the principal taxa throughout the 13 years of sampling. However, the total number of taxa reported in the more recent studies appears to be greater.

In summary, the macroinvertebrate community within the Conestoga River Basin at the 10 sites generally appears to be stable and exhibits a composition indicative of "good" water quality conditions. The time of year the collections were made and the fact that very high flows were encountered in the 1989 field samples contributes to some of the differences within and between sites.

7.3 SMALL WATERSHED

The 5.82 mi^2 Small Watershed (fig. 6-3), about 50 percent underlain by carbonate rock, is drained by the Little Conestoga Creek and includes all or part of 43 farms (fig. 6-4). Agriculture in the watershed is concentrated in the carbonate area. Water-quality monitoring was completed from April 1984 through March 1986 prior to BMP implementation (pre-BMP period), and from April 1986 through September 1989 during implementation (post-BMP period). Two 1.4 mi^2 subbasins, the Nutrient and Nonnutrient Subbasins, located within the watershed and differing in level of BMP implementation were delineated to facilitate determination of the effects of BMP implementation. (See Section 6.)

7.3.1 Small Watershed Precipitation

The long-term average annual precipitation for the Small Watershed is approximately 41.5 inches based on precipitation record for the NOAA precipitation station near Morgantown, Pennsylvania. Annual precipitation measured in the Small Watershed is listed along with the long-term normal in table 7.3-1. Of the five years, 3 were within 5 percent of the long-term average. The two remaining years, which were the first year of the pre-BMP period and the first year of the post-BMP period were 14 percent and 25 percent below the long-term average, respectively. The monthly distribution of precipitation for the study period is shown in figure 7.3-1.

7.3.2 Small Watershed Agricultural Activities

Of the 16 farms in the Nutrient-Management Subbasin (fig. 6-4), 14 provided agricultural-activity data and 11 of the 14 farms providing data maintained animal populations. Of the farms that did not provide information, one represents 9 percent of the basin acreage and the other comprises less than 1 percent of the basin. Corn was the predominant crop in the subbasin; it accounted for over 50 percent of the agricultural land use (table 7.3-2). Farmers in the study area generally rotated crops using a schedule of 2 years for corn and 3 years for alfalfa. Data provided by the farmers indicated that about 40 percent of the total crop acreage in the Nutrient-Management Subbasin was rotated to a different crop each year. Most of the pasture land in the Nutrient-Management Subbasin borders stream channels which allowed grazing livestock free access to the stream. Nonagricultural uses accounted for 9 percent of land use and included: housing, a school, forest, and three small businesses.

Table 7.3-1.--Comparison of annual precipitation at the Small Watershed and long-term average for Morgantown, Pennsylvania

Period	Precipitation, in inches	Long-term average[1]
April 1984 through March 1985	35.7	41.5
April 1985 through March 1986	39.6	41.5
April 1986 through March 1987	31.0	41.5
April 1987 through March 1988	40.8	41.5
April 1988 through March 1989	41.8	41.5
April 1989 through March 1990	28.4	22.9

[1] Long-term average precipitation based on 30 years (1951-80) of record from the National Oceanic and Atmospheric Administration weather station at Morgantown, Pennsylvania.

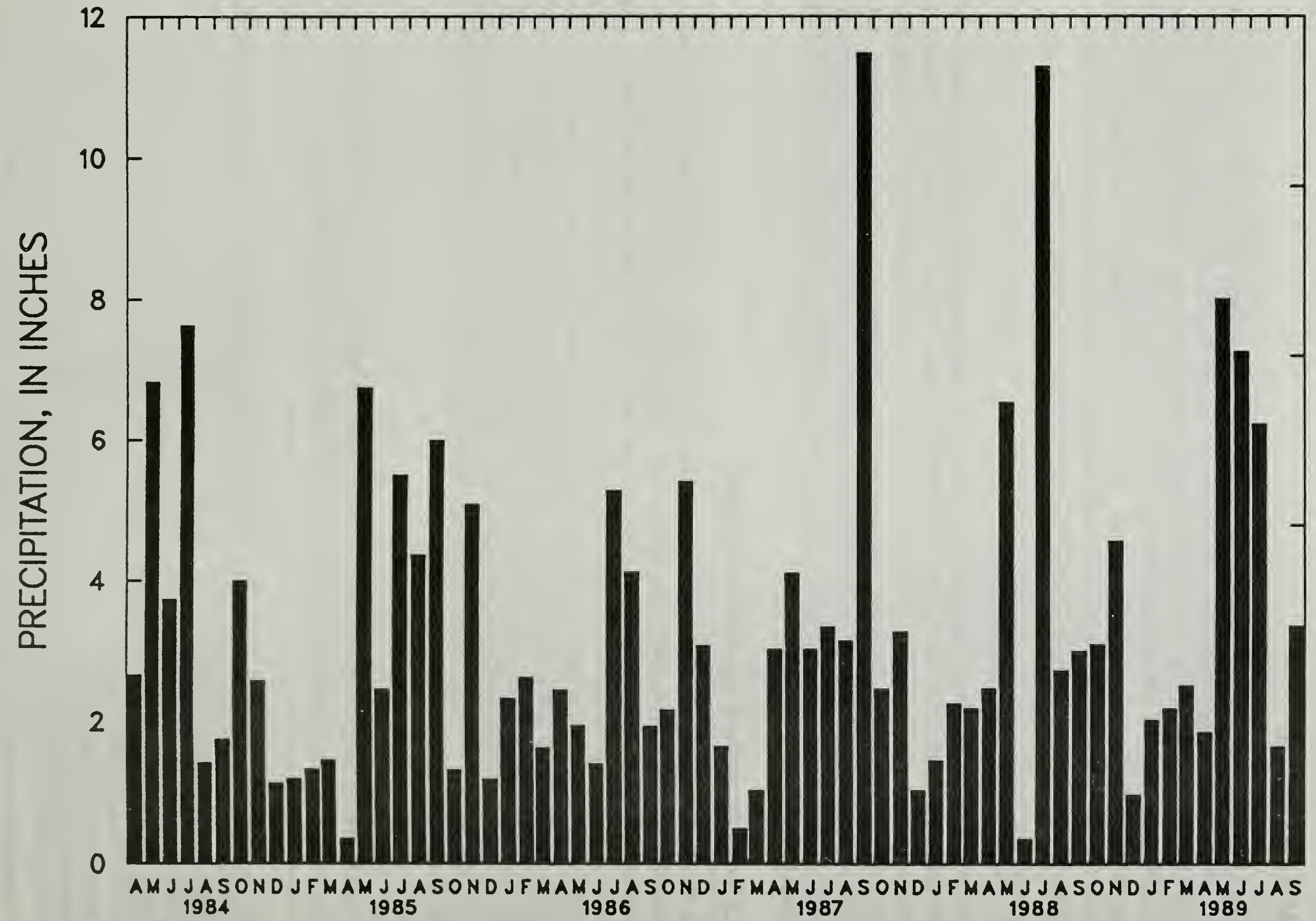


Figure 7.3-1.--Monthly precipitation in the Small Watershed.

Table 7.3-2.--Estimated agricultural land use percentages in the Nutrient-Management Subbasin, April 1, 1984, through March 31, 1986

Land use	Percentage of total acreage	Percentage of agricultural acreage
Agricultural	78	
corn		52
hay		22
pasture		8
noncropland		18
Nonagricultural	22	
Total	100	

Because only 9 percent of the land is devoted to nonagricultural purposes and because the number of people residing in the Nutrient-Management subbasin is small compared to the animal populations, the potential for nutrient contributions from septic systems was considered minimal.

Nutrient management was implemented in the Nutrient-Management Subbasin in April 1986 and included fertilizer management on 10 of the cooperating farms, and animal-waste management on one farm. Fertilizer management which includes both manure and commercial fertilizer consisted of having each farmer follow a nutrient-management plan. The nutrient-management plan supplied the farmer with nutrient application recommendations which would allow desired crop yields while minimizing nutrient availability for transport to ground water or in surface runoff. Deposition of nutrients by grazing livestock was not included in the nutrient-management BMP.

Recommended application rates for each field were determined by factoring in crop acreage, the quantity and nutrient content of manures and commercial fertilizers to be applied, estimates of soil-nutrient reserves, and any reliable historical nutrient-application data for the farm. Animal-waste management was implemented to minimize nutrient losses through improved waste-handling practices such as improved storage facilities and scheduled nutrient application times. Under the nutrient-management guidelines, preferred nutrient application scheduling may require manure storage for periods of up to 180 days. Prior to nutrient management farms, in the Nutrient-Management Subbasin typically had manure storage capacities of up to 35 days maximum. As a result, even under field conditions conducive to nutrient losses, routine field applications were necessary to prevent overloading of storage facilities. For the nutrient-management period one farm, Farm H (fig. 6-4), increased its storage capacity to 200 days with the construction of a 250,000 gallon concrete storage tank. Manure storage capacities at the other farms remained limited to about 4 or 5 weeks.

Although some farms did not receive their plans on schedule, the post-BMP period formally began on April 1, 1986 with 11 of 14 farms implementing some phase of nutrient management. Apart from cooperation with the RCWP program, some farmers may have made changes in their farming practices as a result of discussions or interaction with USDA-SCS and Penn State Cooperative Extension personnel. Between 1986 and 1989 several modifications were made to the method used to generate nutrient-management plans and in 1989 nutrient-management plans for many of the farms in the Nutrient-Management Subbasin were revised to incorporate those modifications.

Animal populations in the Nutrient-Management Subbasin were substantial and diverse; they included beef and dairy cattle, sheep, swine, chickens, turkeys, horses, and mules. Animal populations varied considerably from year to year and within a year but generally were stable in proportion. On average, the majority of the population was comprised of, by weight, about 50 percent poultry, 30 percent dairy, and 15 percent swine.

The Conestoga Headwaters Plan of Work (U.S. Department of Agriculture, 1982) classified farms with more than 1.5 AU/acre (animal units per acre) as being critical areas in terms of nonpoint-source agricultural pollution. Animal densities on most farms in the Nutrient-Management Subbasin exceeded the critical value (table 7.3-3).

Table 7.3-3.--Animal densities on farms in the Nutrient-Management Subbasin based on total crop acreage where manure may be applied

[AU, animal units]

Farm[1]	Crop acreage (acres)	Animal density (AU/acre)
A, A'[2]	106	1.3
B	75	1.2
D	55	10.0
E	27	.9
G	82	1.2
H	32	3.1
I	44	1.6
J	126	1.1
L	70	1.6
M	34	2.0

[1] Location on figure 6-4.
[2] One farmer operates both farms.

Estimates of the production of manure and manure nutrients in the Nutrient-Management Subbasin were made to permit verification of reported application data and inclusion of nutrient contributions from grazing livestock. Although an effort was made to collect comprehensive data on the production and disposition of manure nutrients within the subbasin, it was determined that a substantial amount of manure production could not be accounted for. A large portion of the "missing" production was probably applied to the outside-of-basin portions of cropland on farms that straddled the subbasin boundary. Because this production did not leave the farm on which it was produced, it was not recorded as export. Estimates of manure production were determined by multiplying values listed in table 7.3-4 for annual manure production by the average number of animal units. The estimates were based on animal unit averages for the pre-BMP and post-BMP periods. Averages were used because the actual number of animal units varied throughout the study period. Nutrient production estimates were calculated by multiplying manure production values by the nutrient content values listed in table 7.3-4. Estimates for manure nutrient production in the Nutrient-Management Subbasin are shown in table 7.3-5. A total of about 1,100,000 lb of nitrogen and 280,000 lb of phosphorus were contained in manures produced on farms in the Nutrient-Management Subbasin during the study period.

The average annual nutrient production was 208,000 and 196,000 lb of nitrogen and 52,600 and 49,400 lb of phosphorus in the pre-BMP and post-BMP periods, respectively. Annual post-BMP nutrient production decreased by 6 percent due to a decrease in the total number of animal units.

Nutrient-input sources in the Nutrient-Management Subbasin included manure, commercial fertilizer, legumes, and precipitation. Manure and commercial fertilizer applications to cropland were the two largest inputs. Pasture land deposition of manure by grazing livestock was the third largest input. Precipitation and plowdown of legumes were estimated to input a small, less than 6 percent, additional amount of nitrogen. Cropland application of nitrogen and phosphorus as recorded by farmers in the Nutrient-Management Subbasin is summarized by month in figure 7.3-2 and by year in table 7.3-6. Average annual

Table 7.3-4.--Manure production and nutrient content of manure by animal type

[tons/yr, tons per year; lb/ton, pounds per ton]

Animal type	Estimated manure produced by one animal unit[1] (tons/yr)[2]	Estimated manure produced by one animal unit[1] (percent solids)[3]	Nutrient content[3] (lb/ton) Nitrogen	Nutrient content[3] (lb/ton) Phosphorus
Dairy cows	15.5	15	10	1.8
Beef cattle	11.0	15	11	3.5
Swine	8.8	14	14	4.4
Poultry	11.0	25	30	8.8
Sheep	6.6	25	22	3.5
Horse/Mule	16.6	21	12	2.2

[1] One animal unit is equivalent to 1,000 pounds of animal weight.

[2] U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, written commun., 1985.

[3] Pennsylvania Department of Environmental Resources, Bureau of Water Quality Management, Manure Management For Environmental Protection.

Table 7.3-5.--Manure and nutrient production in the Nutrient-Management Subbasin

[AU, animal units; pre-BMP, April 1, 1984 through March 31, 1986; post-BMP, April 1, 1986 through September 30, 1989; lb, pound]

Manure type	Period	AU	Manure production (tons)	Nitrogen produced (lb)	Phosphorus produced (lb)
Dairy	Pre-BMP	476	14,760	147,600	26,570
	Post-BMP	472	25,610	256,100	46,100
Beef	Pre-BMP	120	2,640	29,040	9,240
	Post-BMP	107	4,120	45,320	14,420
Swine	Pre-BMP	218	3,840	53,760	16,900
	Post-BMP	188	5,790	81,060	25,480
Poultry	Pre-BMP	254	5,590	167,700	49,190
	Post-BMP	247	9,510	285,300	83,690
Sheep	Pre-BMP	30	396	8,710	1,390
	Post-BMP	0	0	0	0
Horse/Mule	Pre-BMP	26	863	10,360	1,900
	Post-BMP	26	1,510	18,120	3,320
Annual average	Pre-BMP	1,124	14,050	208,600	52,600
	Post-BMP	1,040	13,300	195,000	49,430

cropland applications of nitrogen and phosphorus decreased 32 percent and 35 percent, respectively, from the pre-BMP to post-BMP period. However, actual annual nutrient applications varied substantially. About 78 percent of the total 534,000 lb of nitrogen and 135,700 lb of phosphorus applied in the Nutrient-Management Subbasin came from manure. The input of nutrients from grazing livestock averaged, annually, 22,000 lb and 18,000 lb of nitrogen and 4,200 lb and 3,500 lb of phosphorus for the pre-BMP and post-BMP period respectively.

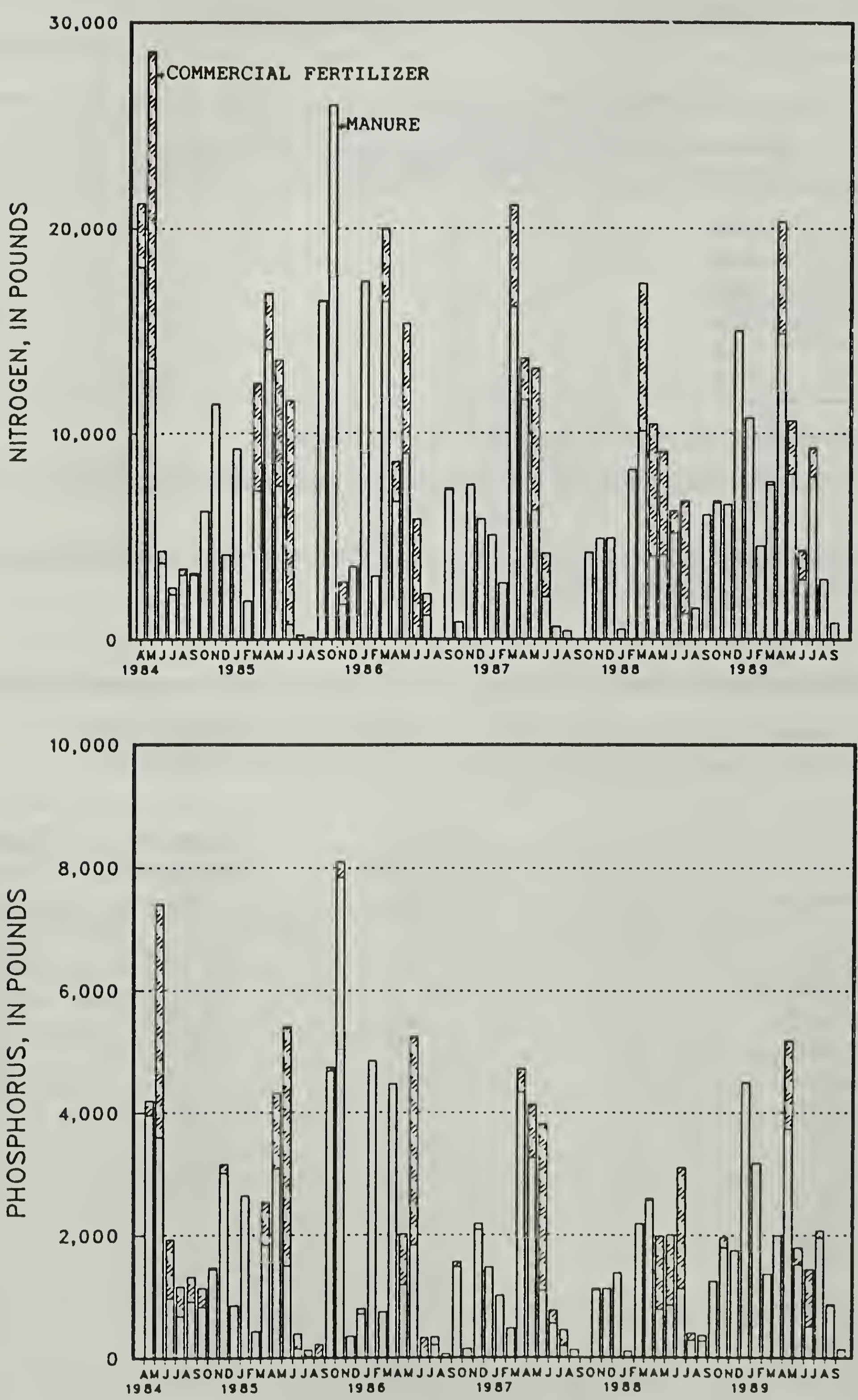


Figure 7.3-2.--Monthly inputs of nitrogen (above) and phosphorus (below) from manure- and commercial-fertilizer applications in the Nutrient-Management Subbasin.

Table 7.3-6.--Nutrient applications to cropland in the Nutrient-Management Subbasin, in pounds

Date	Period	Nitrogen: Manure +	Nitrogen: Commercial fertilizer =	Nitrogen: Total	Phosphorus: Manure +	Phosphorus: Commercial fertilizer =	Phosphorus: Total
April 1984 through March 1985	Pre-BMP	83,500	25,100	108,600	21,200	7,100	28,300
April 1985 through March 1986	Pre-BMP	107,000	24,600	131,600	28,400	6,100	34,500
April 1986 through March 1987	Post-BMP	62,300	20,200	82,500	14,300	5,300	19,600
April 1987 through March 1988	Post-BMP	53,800	18,300	72,100	13,700	4,200	17,900
April 1988 through March 1989	Post-BMP	73,000	18,300	91,300	19,200	4,700	23,900
April 1989 through September 1989	Post-BMP	37,400	10,900	48,300	8,700	2,800	11,500
Annual average	Pre-BMP	95,250	24,850	120,100	24,8000	6,600	31,400
	Post-BMP[1]	63,000	18,900	81,900	15,700	4,700	20,400

[1] April 1989 through September 1989 excluded when calculating average.

The methods of applying manure and the timing of applications affect the amount of nutrients that ultimately becomes available for the crops, surface runoff, or leaching to the ground water. If manure is simply applied to the surface, then a significant amount of the nitrogen can volatilize to the atmosphere in the form of ammonia. As much as 30 percent of the nitrogen can be lost from volatilization to the atmosphere within 7 days if the manure is not incorporated into the soil shortly after it is applied (Pennsylvania Department of Environmental Resources, 1986). Volatilization also will increase as air temperatures increase. Van Breemen and others (1982), however, suggest that substantial amounts of the nitrogen lost from volatilization can return to the soil surface in precipitation.

7.3.3 Small Watershed Soils

Soil maps from the Lancaster County Soil Survey (U.S. Department of Agriculture, 1985) were digitized to compare soils in the Small Watershed, the Nutrient-Management Subbasin, and the Control Subbasin. The soils in the Small Watershed and those of the Nutrient-Management Subbasin are nearly the same; 47 and 50 percent are noncarbonate, 41 and 36 percent are carbonate, and 12 and 14 percent are alluvial, respectively. In the Control Subbasin, 71 percent of the soils are noncarbonate, 18 percent carbonate, and 11 percent alluvial.

The soil pH of 40 fields on 10 farms in the Nutrient-Management Subbasin was measured between April 5-15, 1984. Soil pH ranged from 6.2 at a field at farm D (fig. 7.3-3) to 7.3 at a field at farm E. The average pH for the 10 farms, calculated as the mean of the hydrogen-ion concentrations, ranged from 6.5 to 7.2.

Concentrations of soil nutrients in the Nutrient-Management Subbasin (figs. 7.3-3 and 7.3-4) were highly variable between fields and between Fall and Spring samples, especially for nitrate nitrogen. The amount of soluble nitrate at the 24 to 48 in. depth was often higher than the amount in the top 8 in. of the soil column indicating the high mobility of nitrate. Soluble phosphorus was usually concentrated in the top 8 in. of the soil column probably because of binding to soil particles. Exceptions are shown at Farm H, where

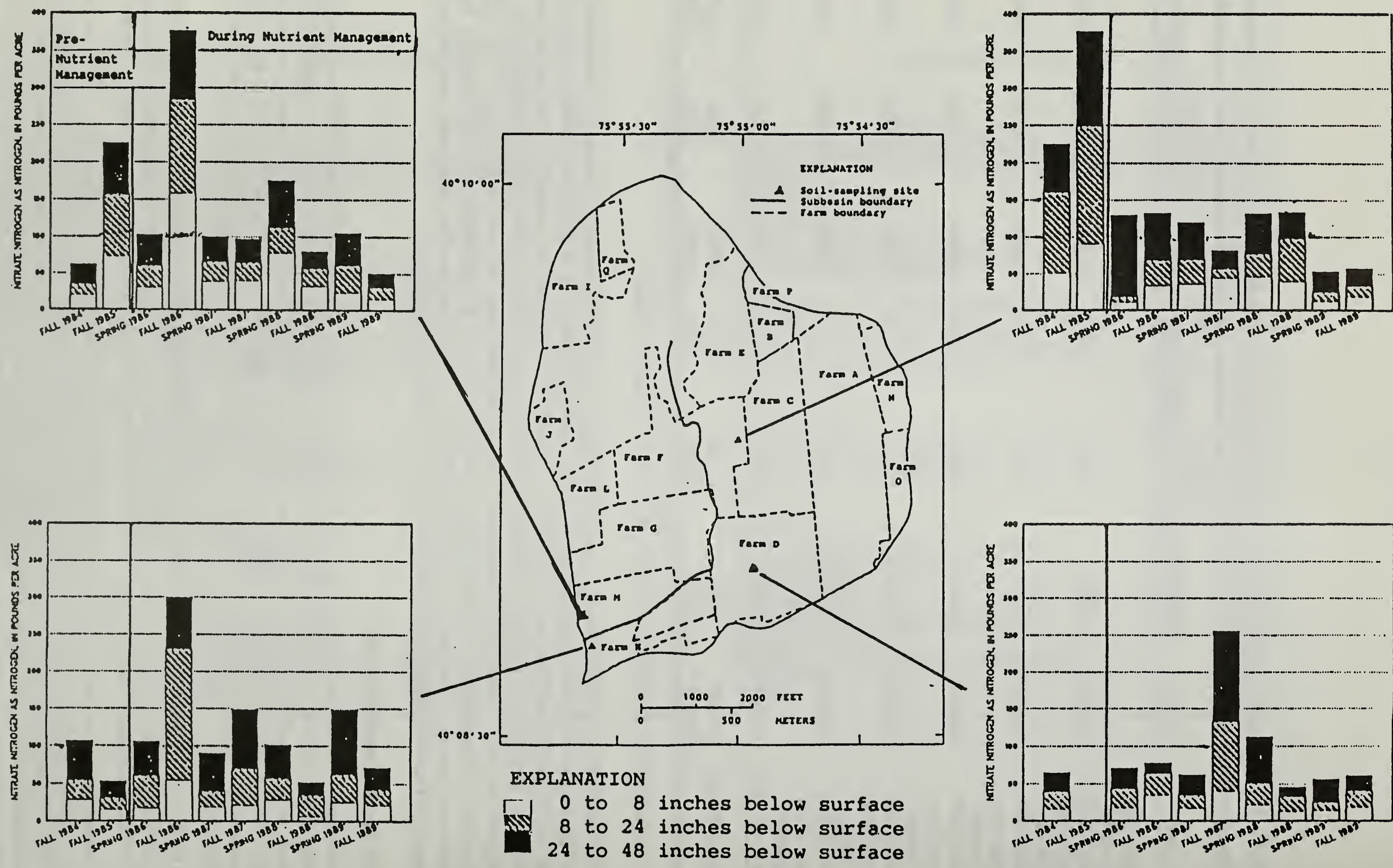


Figure 7.3-3.--Soluble nitrate-nitrogen concentrations in the soil prior to and during nutrient management on four fields in the Nutrient-Management Subbasin.

a substantial amount of phosphorus was detected in the soil at a depth between 24 to 48 in. during the Fall of 1984, and 1985, and the Spring and Fall of 1986. Although no specific reason could be found for these large phosphorus concentrations at depth, groundwater which normally has below detection limit concentrations of phosphorus from a seep nearby showed larger than expected phosphorus concentrations.

At farms H and M, average soil concentrations of soluble nitrogen were lower, and average concentrations of soluble phosphorus were usually higher in the Fall than in the Spring. This suggests that nitrate leached downward below the 48 in. soil profile during the nongrowing season after crops were harvested. The higher concentrations of phosphorus in the soil during the Spring were probably due to Fall and Winter surface applications of manure and from the decomposition of crop residue including the corn stubble and roots. These results concur with Harley and others, (1951) Jones and Bromfield, (1969) Kline, (1969) and Timmons and others, (1970) who report that 69 to 80 percent of the total phosphorus may be leached from dormant or dead vegetation. Soil nutrient concentrations at farms D and F showed no discernible seasonal behavior.

The range in average concentrations of soluble nitrogen at the four fields was reduced from a minimum of 65 lb/acre and maximum of 300 lb/acre of nitrogen prior to nutrient management to a minimum of 93 lb/acre and maximum of 140 lb/acre of nitrogen during the management phase. The range in average concentrations of soluble phosphorus changed from a minimum of 1.8 lb/acre and maximum of 14 lb/acre of phosphorus prior to nutrient management to a minimum of 6.5 lb/acre and a maximum of 18 lb/acre during nutrient management. Because the averages are calculated on limited data, two samples for the pre-management phase and eight samples for the management phase, it is premature to conclude that concentrations of soluble nitrogen and soluble phosphorus in the soils are becoming more uniform throughout the subbasin as the result of nutrient management.

Soil nutrient concentrations, as reflected by the samples collected in the Nutrient-Management Subbasin, are highly variable. Early investigators recognized the varying soil and climatic conditions that make it difficult to collect representative samples of a field, as well as to interpret soil nitrogen measurements. Harmsen and Van Schreven (1955) concluded that reliable interpretations can only be made when dealing with a single soil type, climatic zone, or farming system. Even when samples are taken from the same field, variations may occur for a number of reasons. In the Nutrient-Management Subbasin, uneven spreading of manure and commercial fertilizer at the surface, combined with the different surface and ground-water flow directions of water moving across the fields and through the vadose zone, and the various rates of nitrogen uptake by plants are a few of the factors that alter the amount of nutrients moving through the soil profile and causes concentrations of soluble nutrients between fields and times of sampling.

All of the soil samples collected during the study had concentrations of soluble nitrogen that were greater than the 50 kg N/ha (44.5 lb/acre) recommended by Baker, (1986) to prevent concentrations of nitrate in gravitational water in typical silt loam soils from exceeding the safe drinking water value of 10 mg/L as nitrogen. The maximum concentration of soluble nitrogen in the top four feet of soil was 380 lb/acre measured at Farm F in the fall of 1985, and at Farm M in the fall of 1986. Samples were collected to depths of 96 in. at two farms in the Spring of 1987 to determine if additional soluble nitrogen was present below the root zone. It was determined that at the fields on Farms D and M an additional 37 lb/acre and 51 lb/acre, respectively, of residual nitrate was present in the soil column between 48 in. and 96 in. below the surface. The presence of this nitrate indicates that there is a substantial reserve of soluble nitrogen that is potentially available for leaching to the groundwater, and is below the area normally available for crop utilization. The capacity of this reserve is currently unknown, but its potential for releasing nitrate to the ground water could delay improvements in water quality.

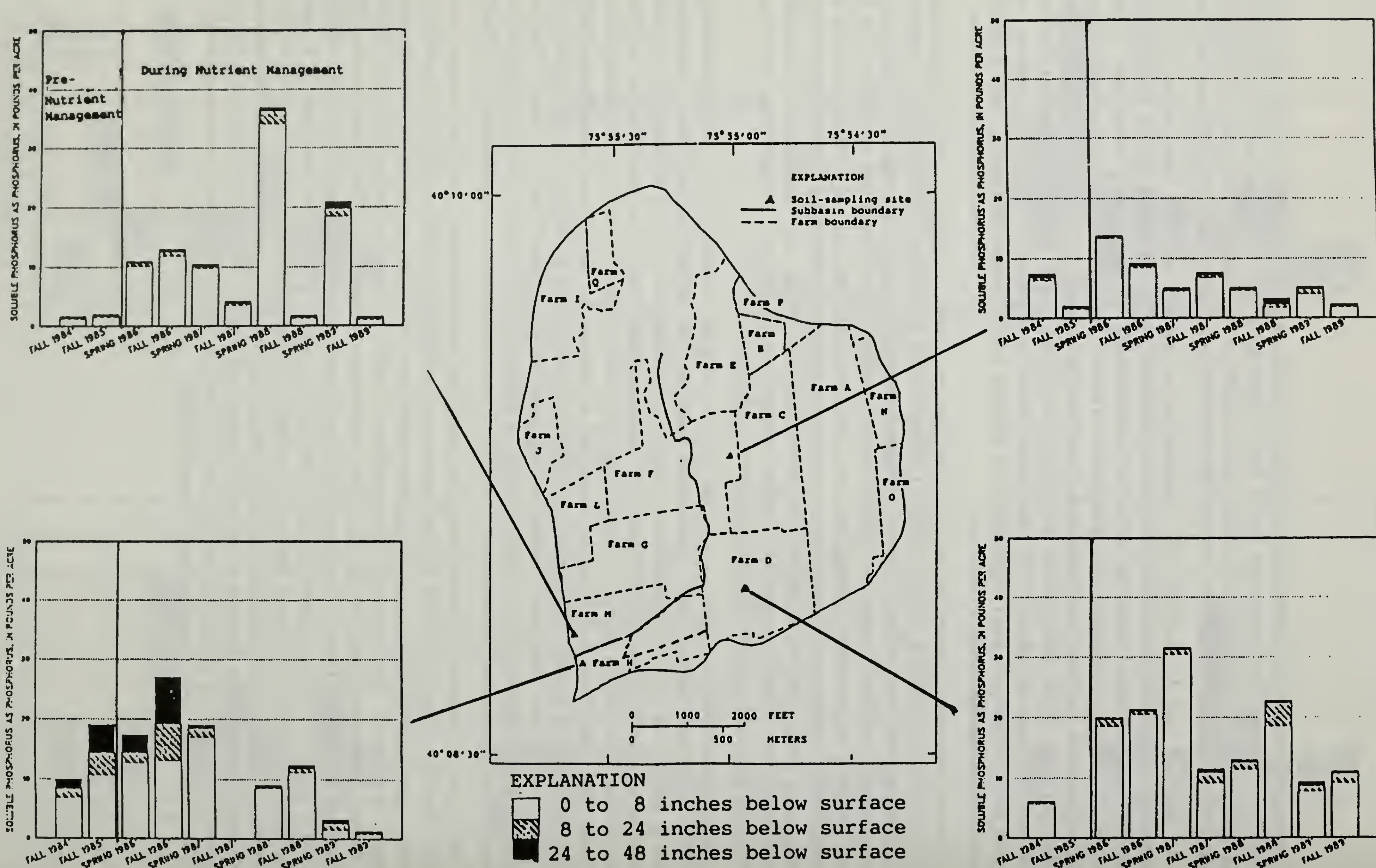


Figure 7.3-4.--Soluble phosphorus concentrations in the soil prior to and during nutrient management on four fields in the Nutrient-Management Subbasin.

7.3.4 Small Watershed Surface-Water Quantity and Quality

Hydrographs of daily mean discharge (figures 7.3-5 and 7.3-6) show streamflow conditions during the study period (April 1984-September 1989) at the continuous record stations, Stations 3, draining the Nutrient-Management Subbasin, and 5, draining the entire Small Watershed (fig. 6-3). At Station 3, the mean daily discharge ranged from a minimum of 0.05 ft^3/s (measured on seven days in October and November 1985) to a maximum of 70 ft^3/s (September 8, 1987); the average daily discharge for the period was 1.3 ft^3/s. At Station 5 the mean daily discharge varied from a minimum of 0.66 ft^3/s (September 17, 1986) to a maximum of 259 ft^3/s (September 8, 1987); the average daily discharge for the period was 7.1 ft^3/s. Tables 7.3-7 and 7.3-8 list mean monthly, seasonal and annual streamflow and base flow for Stations 3 and 5.

At both stations, stream discharge typically increased quickly during a precipitation event then rapidly returned to near base-flow levels. Base flow, as computed by the local minimum method described by Pettyjohn and Henning (1979), contributed between 8 and 99 percent of the monthly streamflow. The maximum percentage of monthly streamflow that was base flow occurred in June 1988 while the lowest percentage occurred in September 1985 at both sites. A small but statistically significant positive trend in total monthly discharge was detected at Station 3 using the seasonal Kendall test. But, no trend was detected in base-flow discharge (table 7.3-9). A significant positive trend was detected in monthly total discharge and monthly base-flow discharge at Station 5.

A pre-BMP to post-BMP comparison of stormflows was made to determine if changes had occurred in the general character of stormflow. Such changes could affect the transport of loads even in storms of equivalent total discharges. Mean storm-day discharge and the difference between minimum and maximum discharge for the day were selected as factors for comparison rather than total storm-day discharge. Unlike total storm-day discharge alone, the combination of mean storm-day discharge and the difference between minimum and maximum discharge for a storm day contain greater information about a storm-day hydrograph.

The distribution of mean storm-day discharges at Station 5 did not change substantially from the pre-BMP to the post-BMP period for the majority of the storms; the median storm-day discharge was 14.0 cubic feet per second in both pre-BMP and post-BMP period. However, the upper 30 percent of storm days showed decreased mean discharges and increased minimum to maximum discharge differences. This change indicates that in the post-BMP period a greater percentage of the larger stormflows were of shorter duration and greater maximum discharge than those in the pre-BMP. A change in the rainfall intensity/duration characteristics, land use, or a combination of these factors could have caused these stormflow changes.

At Station 3, mean storm-day discharges decreased mostly in the upper 20 percent of discharges. Unlike Station 5, however, minimum to maximum discharge differences decreased also. This decrease indicates that in the post-BMP period the largest storm-day discharges occurred less frequently at Station 3. Although Station 3 and Station 5 are located 3.4 miles apart, it is unlikely that differences in precipitation would have caused the opposing changes in minimum to maximum discharge differences. More likely, changes in cropping patterns and other land-use activity between Stations 3 and 5 were the cause of the opposing changes.

Monthly base-flow nutrient concentration data are summarized in figures 7.3-7 through 7.3-10. The data are separated into the April 1984 through March 1986 pre-BMP period and the April 1986 through September 1989 post-BMP period.

At Stations 1 through 3 (fig. 6-3), all within the Nutrient-Management subbasin, base-flow concentrations of dissolved nitrate plus nitrite whose source is primarily ground-water nitrate increases with downstream distance and suggest an increasing contribution of nitrate enriched ground water to stream base flow. Median concentrations of dissolved ammonia nitrogen, total ammonia plus organic nitrogen, and total phosphorus which are commonly found only in trace concentrations in ground waters of the area were greatest at Station 2. The greater concentrations at Station 2 probably resulted from in-stream conditions particular to that station. Examination of agricultural-activity data and channel characteristics revealed some possible causes. First, beef cattle had year-round pasture and stream access adjacent to and upstream from the station with an attendant deposition of nutrients and disturbance of channel sediments. And secondly, slower stream velocity at Station 2 allowed the accumulation of sediment and any associated phosphorus.

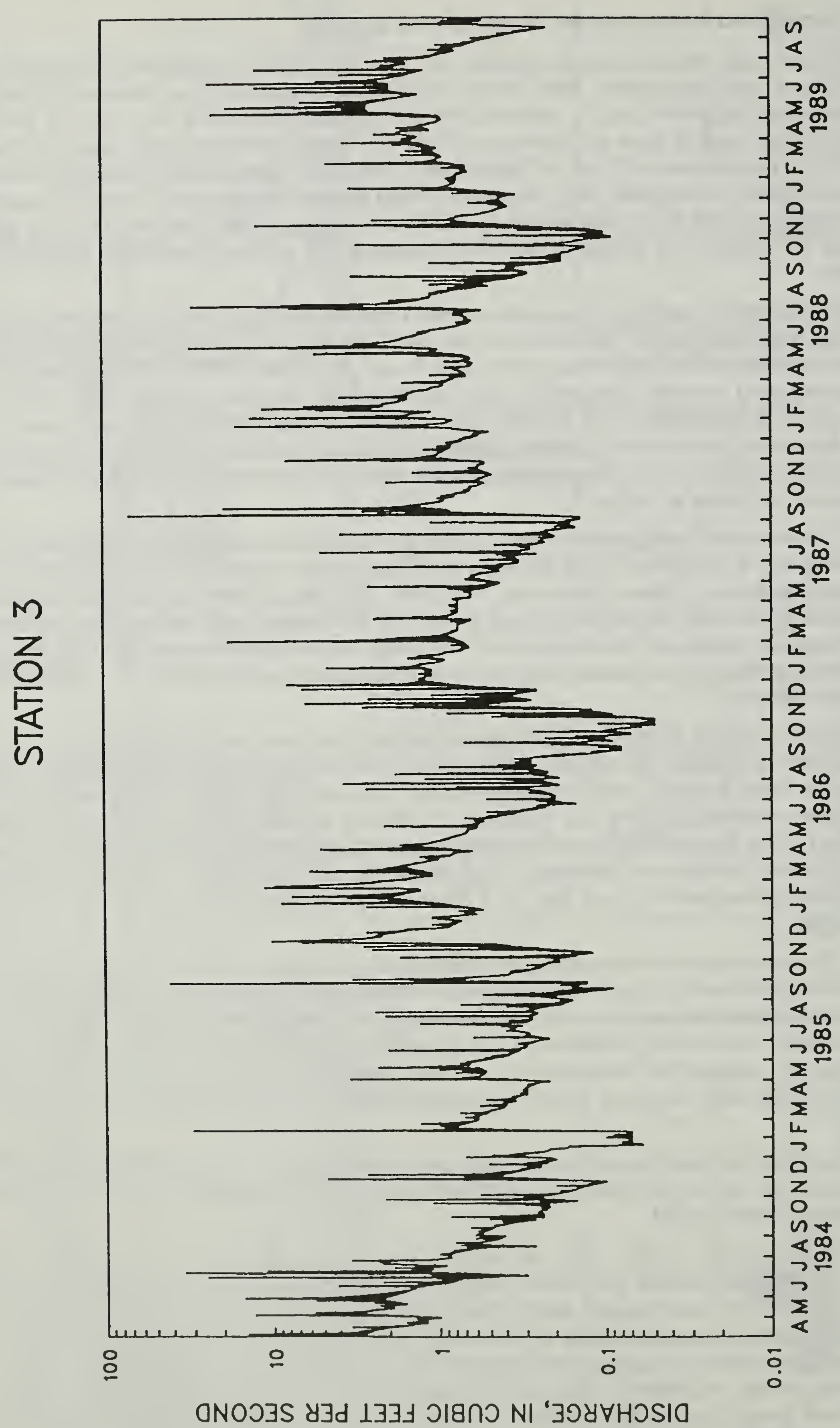


Figure 7.3-5.--Streamflow hydrograph of the Little Conestoga Creek at Station 3 from April 1984 through September 1989.

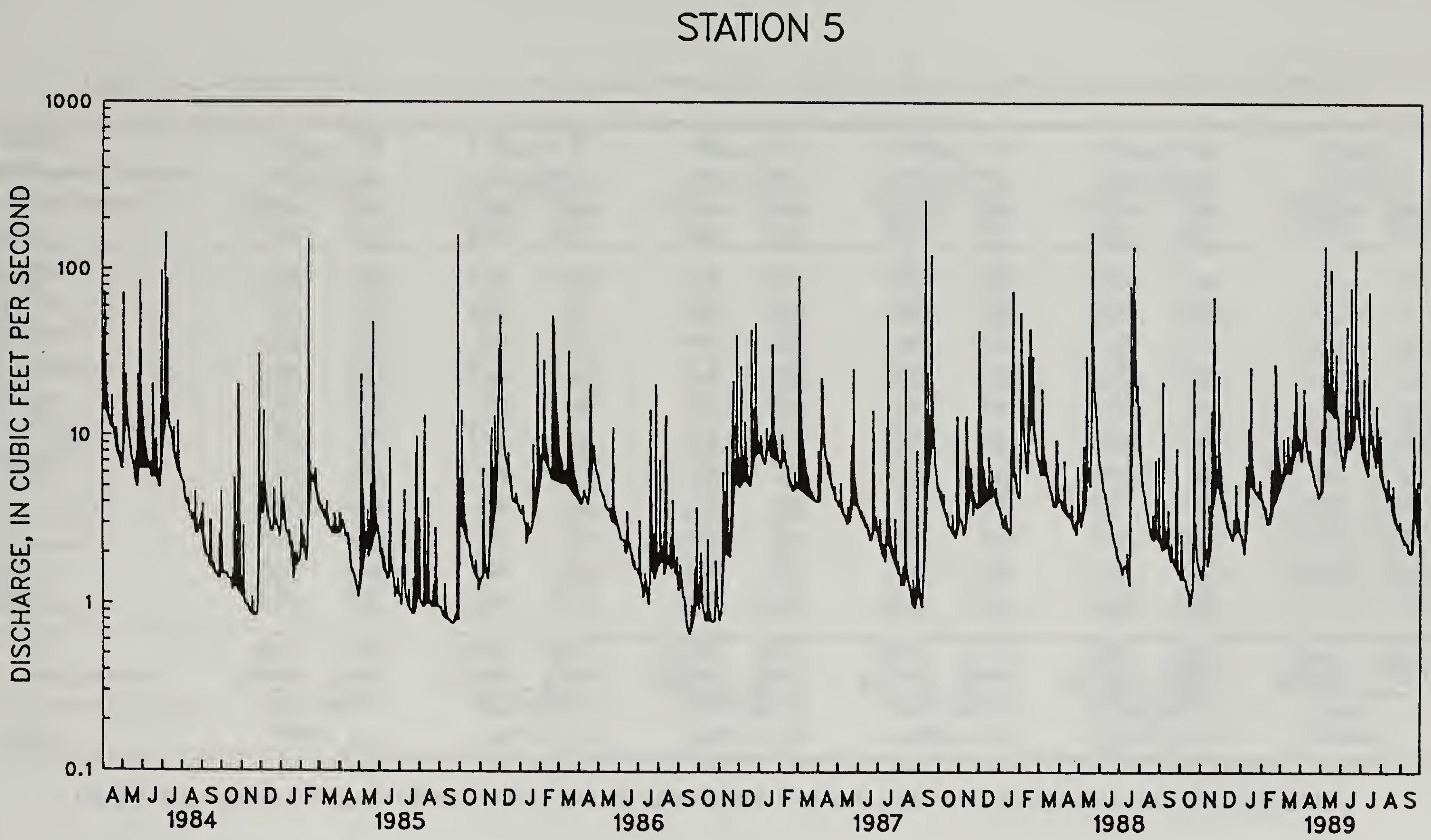


Figure 7.3-6.--Streamflow hydrograph of the Little Conestoga Creek at Station 5 from April 1984 through September 1989.

Table 7.3-7.--Mean monthly, seasonal, and annual streamflow and base flow, in cubic feet per second, at Station 3

	Year 1 1984-1985		Year 2 1985-1986		Year 3 1986-1987		Year 4 1987-1988		Year 5 1988-1989		Year 6 1989	
	Stream-flow	Base flow	Stream-flow	Base flow	Stream-flow	Base flow	Stream-flow	Base flow	Stream-flow	Base flow	Stream-flow	Base flow
April	2.89	1.92	0.36	0.34	1.40	0.98	0.92	0.79	0.75	0.70	1.33	1.24
May	3.71	2.12	.80	.58	.79	.68	.72	.59	2.95	1.33	4.16	2.10
June	1.90	1.33	.46	.38	.35	.31	.59	.48	1.08	1.04	3.54	1.86
July	3.60	1.13	.40	.33	.54	.23	.51	.30	2.74	1.34	2.14	1.53
August	.70	.62	.47	.24	.42	.25	.37	.19	.90	.78	.82	.74
September	.48	.44	1.70	.15	.18	.14	4.08	.77	.49	.30	.51	.43
October	.42	.22	.49	.38	.10	.08	.77	.68	.33	.16		
November	.36	.16	1.32	.70	.76	.22	1.10	.56	.92	.30		
December	.45	.30	1.98	1.83	1.45	.52	.98	.90	.52	.50		
January	.21	.18	1.42	.85	1.32	1.15	1.42	.80	.80	.64		
February	1.70	.40	3.76	2.82	.93	.84	3.30	1.86	1.04	.78		
March	.54	.51	1.84	1.37	1.66	.79	1.33	1.19	1.34	1.13		
Growing season	2.22	1.26	.70	.34	.61	.43	1.19	.52	1.50	.92	2.09	1.32
Nongrowing season	.60	.29	1.77	1.30	1.04	.60	1.47	.99	.82	.58		
Annual	1.41	.78	1.23	.82	.83	.51	1.33	.75	1.16	.75		

Table 7.3-8.--Mean monthly, seasonal, and annual streamflow and base flow, in cubic feet per second, at Station 5

	Year 1 1984-1985		Year 2 1985-1986		Year 3 1986-1987		Year 4 1987-1988		Year 5 1988-1989		Year 6 1989	
	Stream-flow	Base flow	Stream-flow	Base flow	Stream-flow	Base flow	Stream-flow	Base flow	Stream-flow	Base flow	Stream-flow	Base flow
April	15.25	10.85	2.13	2.05	6.71	5.15	7.29	6.00	3.71	3.27	7.44	6.81
May	15.88	7.70	5.67	2.11	4.16	3.59	4.91	3.55	15.91	8.78	23.57	11.39
June	8.46	5.83	1.95	1.53	2.15	2.03	3.51	2.87	3.47	3.44	20.78	9.49
July	20.97	8.86	1.97	1.16	3.11	1.38	4.11	1.97	18.83	10.08	11.25	7.41
August	3.76	3.58	1.87	.98	2.82	1.62	2.37	1.22	3.84	3.40	4.12	3.84
September	2.04	1.78	6.60	.81	1.16	.94	20.33	4.88	3.24	1.90	2.98	2.45
October	2.74	1.35	2.78	2.03	1.07	.90	3.93	3.14	2.36	1.49		
November	2.43	1.04	7.26	4.48	6.74	2.78	7.27	3.53	7.84	2.95		
December	3.89	3.21	7.81	7.41	12.06	6.03	5.80	4.08	3.44	2.97		
January	2.57	2.30	5.71	3.33	9.91	7.39	7.06	3.92	5.63	3.90		
February	9.76	3.53	15.70	6.03	6.23	5.73	17.01	9.63	6.46	3.73		
March	3.15	2.97	8.05	4.78	10.04	4.38	6.36	4.92	8.60	6.62		
Growing season	11.10	6.44	3.36	1.44	3.35	2.45	7.03	3.40	8.24	5.18	11.70	6.91
Nongrowing season	4.00	2.39	7.76	4.65	7.70	4.52	7.81	4.83	5.70	3.61		
Annual	7.56	4.42	5.56	3.04	5.52	3.48	7.42	4.11	6.97	4.40		

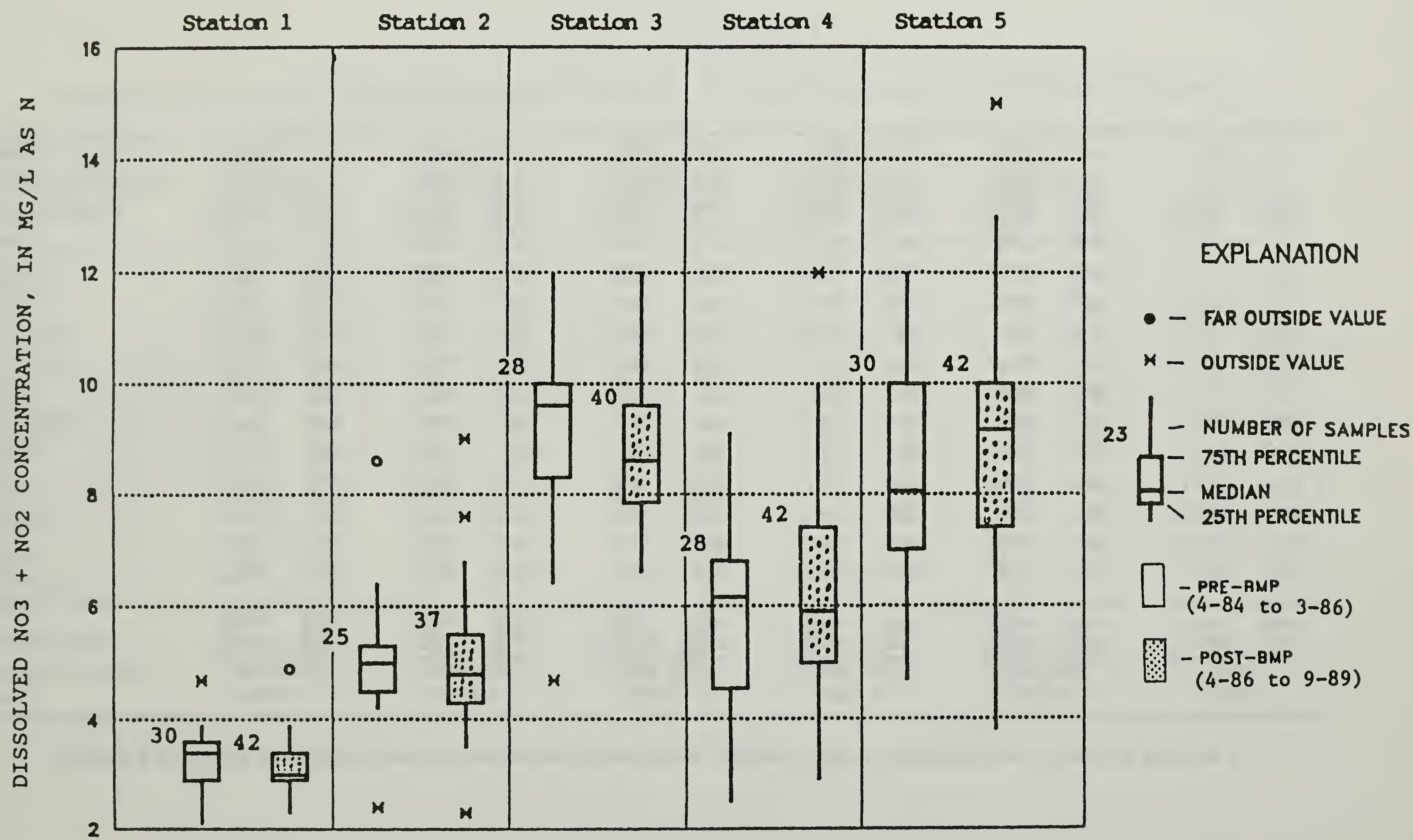


Figure 7.3-7.--Concentrations of dissolved nitrate plus nitrite nitrogen in base flow at Stations 1 through 5.

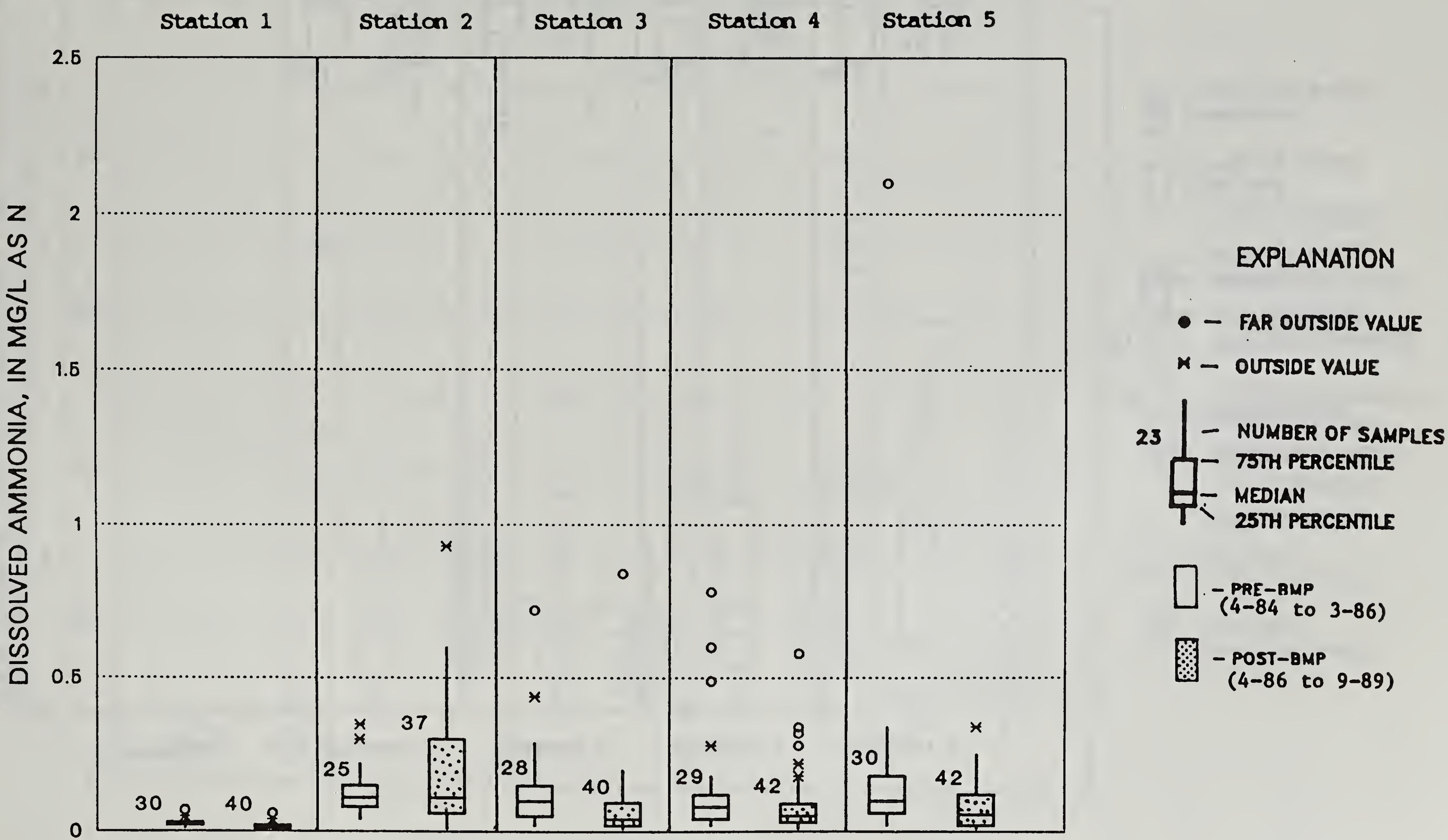


Figure 7.3-8.--Concentrations of dissolved ammonia nitrogen in base flow at Stations 1 through 5.

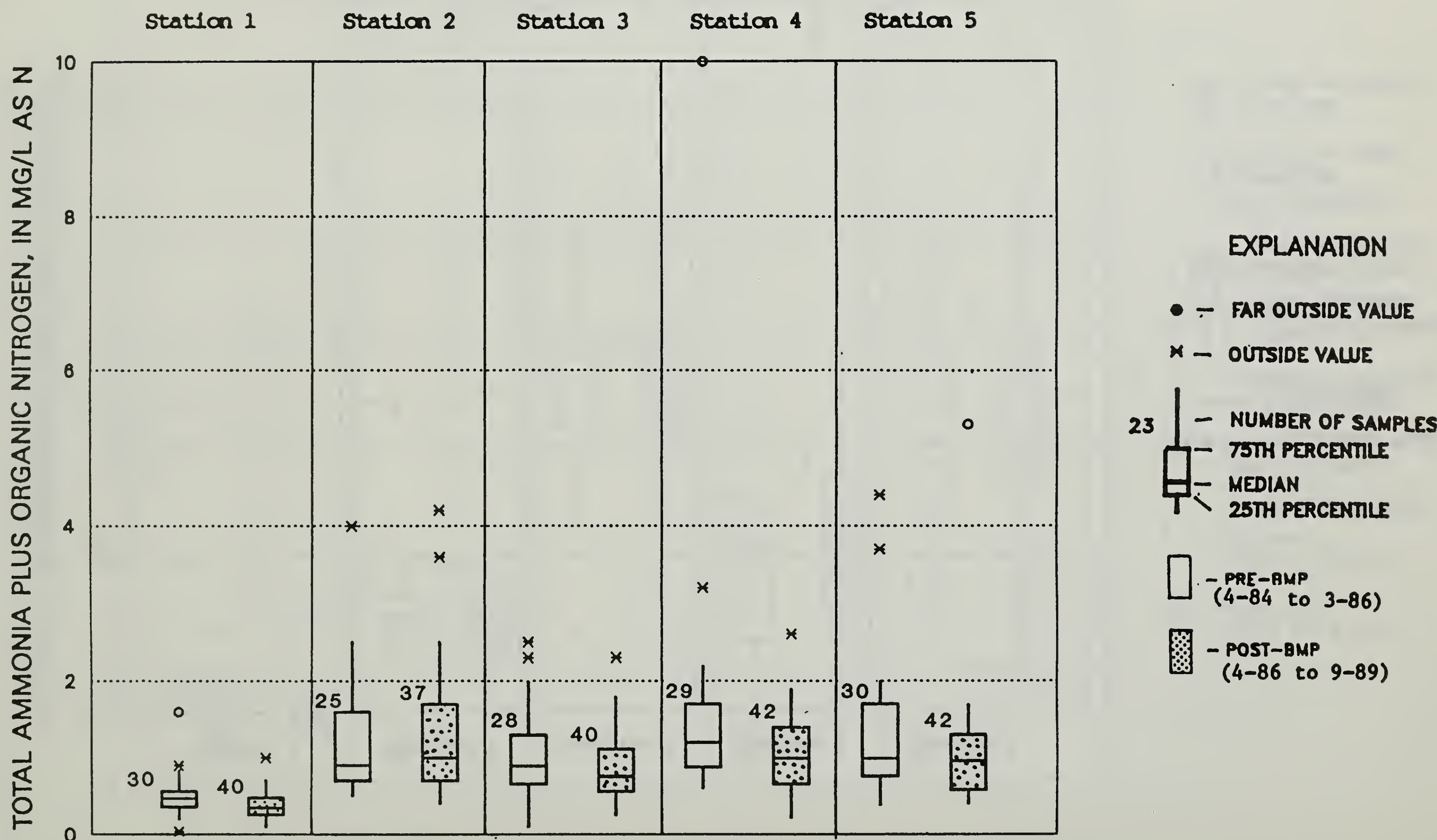


Figure 7.3-9.--Concentrations of total ammonia plus organic nitrogen in base flow at Stations 1 through 5.

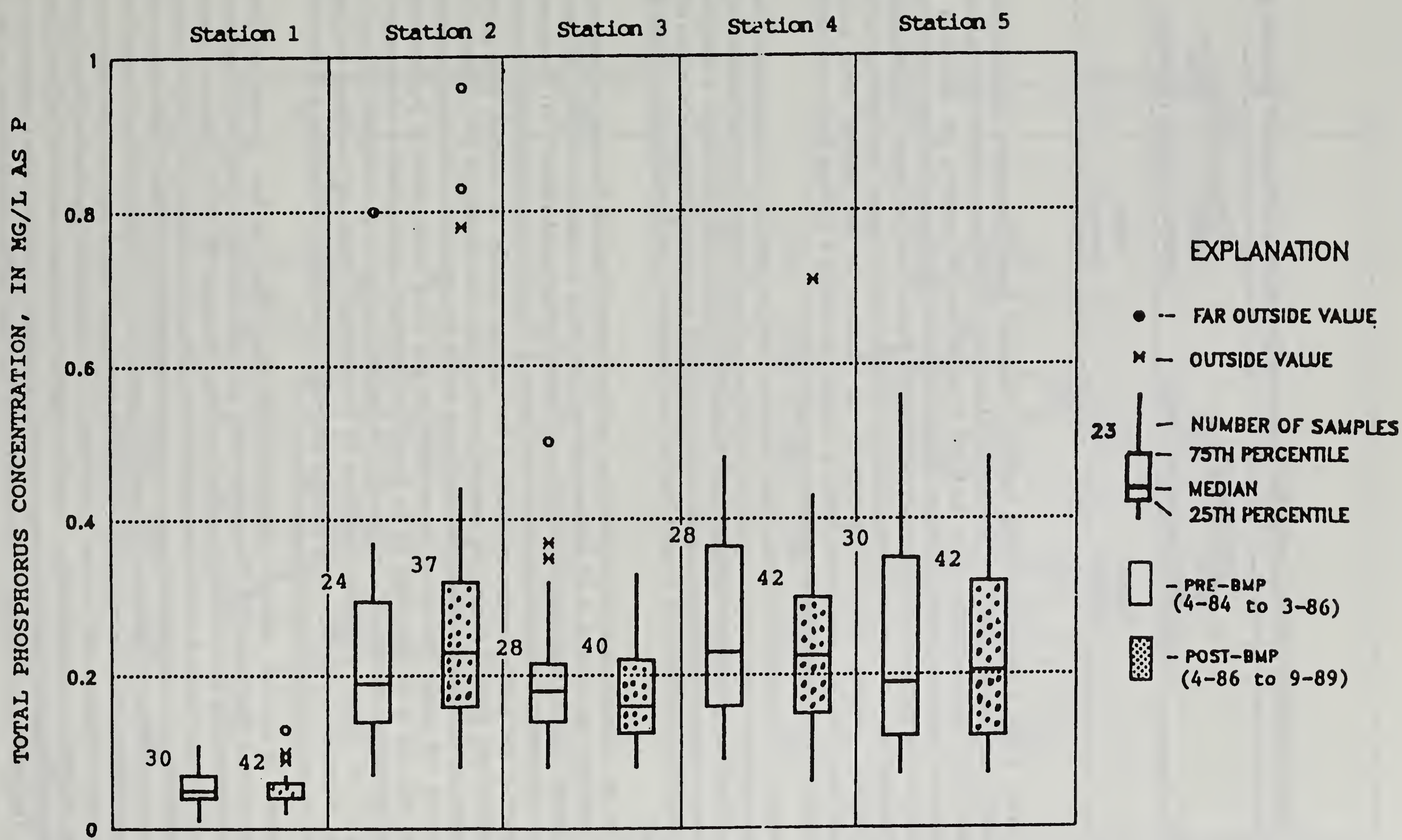


Figure 7.3-10.--Concentrations of total phosphorus in base flow at Stations 1 through 5.

Table 7.3-9.--Trends in total monthly discharges and base-flow discharges at Stations 3 and 5

Station	Total discharge Trend	Total discharge Slope (percent of median discharge)	Base flow discharge Trend	Base flow discharge Slope (percent of median discharge)
3	Increase	1.4	None	–
5	Increase	8.5	Increase	13

At Station 4 (fig. 6-3), in the Control Subbasin, dissolved nitrate plus nitrite concentrations were substantially lower than at Station 3, in the Nutrient-Management Subbasin despite the fact that both drain equal areas with approximately equal land-use proportioning. In contrast, the Station 4 median concentrations of dissolved ammonia nitrogen and total ammonia plus organic nitrogen were very similar to, and median concentrations of total phosphorus slightly greater than the Station 3 concentrations. The relation between base-flow nutrient concentrations at Stations 3 and 4 suggest that nutrient contributions from in-channel processes were similar between the stations but that ground water contributed significantly less nitrate to streamflow at Station 4. Notably, the Station 4 drainage basin was underlain by 23 percent less carbonate rock than the Station 3 drainage basin.

At Station 5, which drained the entire Small Watershed, median base-flow concentrations of dissolved nitrate plus nitrite were similar to concentrations at Station 3 although Station 5 concentrations had greater variation. The drainage basins for Stations 3 and 5 are about equal in their percentage of carbonate rock. Median concentrations of dissolved ammonia nitrogen and total ammonia plus organic nitrogen at Station 5 were similar to those of Stations 2, 3, and 4. Median total-phosphorus concentrations were similar to those of Station 2.

Much of the variation shown in the base-flow nutrient concentrations is the result of seasonal cycles. Seasonal variation was evident at all stations although the range of variation was not the same at all stations; Station 1 had the least seasonal variation and Station 5 the greatest. Figure 7.3-11 shows examples of the seasonal variation of nutrient concentrations at Station 5. Dissolved nitrate plus nitrite concentrations were greatest in the winter months and least in the summer months. In contrast, total phosphorus concentrations were greatest during the summer months. Base-flow discharges and dissolved-oxygen concentrations are normally near the annual minimums during the summer months. At this time base flow is sustained by low nitrate plus nitrite concentration ground water whose source is predominantly the forested upland area of the watershed. At the same time phosphorus concentrations whose source is the streambed sediments is less diluted. Additionally, low dissolved-oxygen concentrations in streamflow are indicative of low oxygen (reducing) conditions in the sediments. Reducing conditions facilitate the conversion of nitrate in streamflow into nitrogen gas which is lost to the atmosphere and the release of phosphorus in streambed sediments to stream water.

In addition to seasonal variation, dissolved nitrate plus nitrite and total phosphorus base-flow concentrations were flow dependent. Flow dependency was demonstrated for these two constituents by a correlation between base-flow concentrations and base-flow discharge (fig. 7.3-12). Dissolved nitrate plus nitrite concentrations increased with increasing base--flow discharge up to about 7 ft^3/s after which further increases in base-flow discharge did not appear to affect concentrations. This characteristic relation between concentration and discharge was also seen at Station 4. Stations 1 and 3, however, did not show this relation; only a minor dilution effect was seen with increases in discharge. Total-phosphorus concentrations at all stations showed a reduction with increases in discharge. Flow dependency was removed from the data by subtracting observed concentrations from a locally weighted scatterplot smooth (LOWESS) (Cleveland, 1979) estimate of the concentration/discharge function and adding the overall mean concentration to the difference. The result was flow-adjusted concentrations which were used in statistical testing of the data.

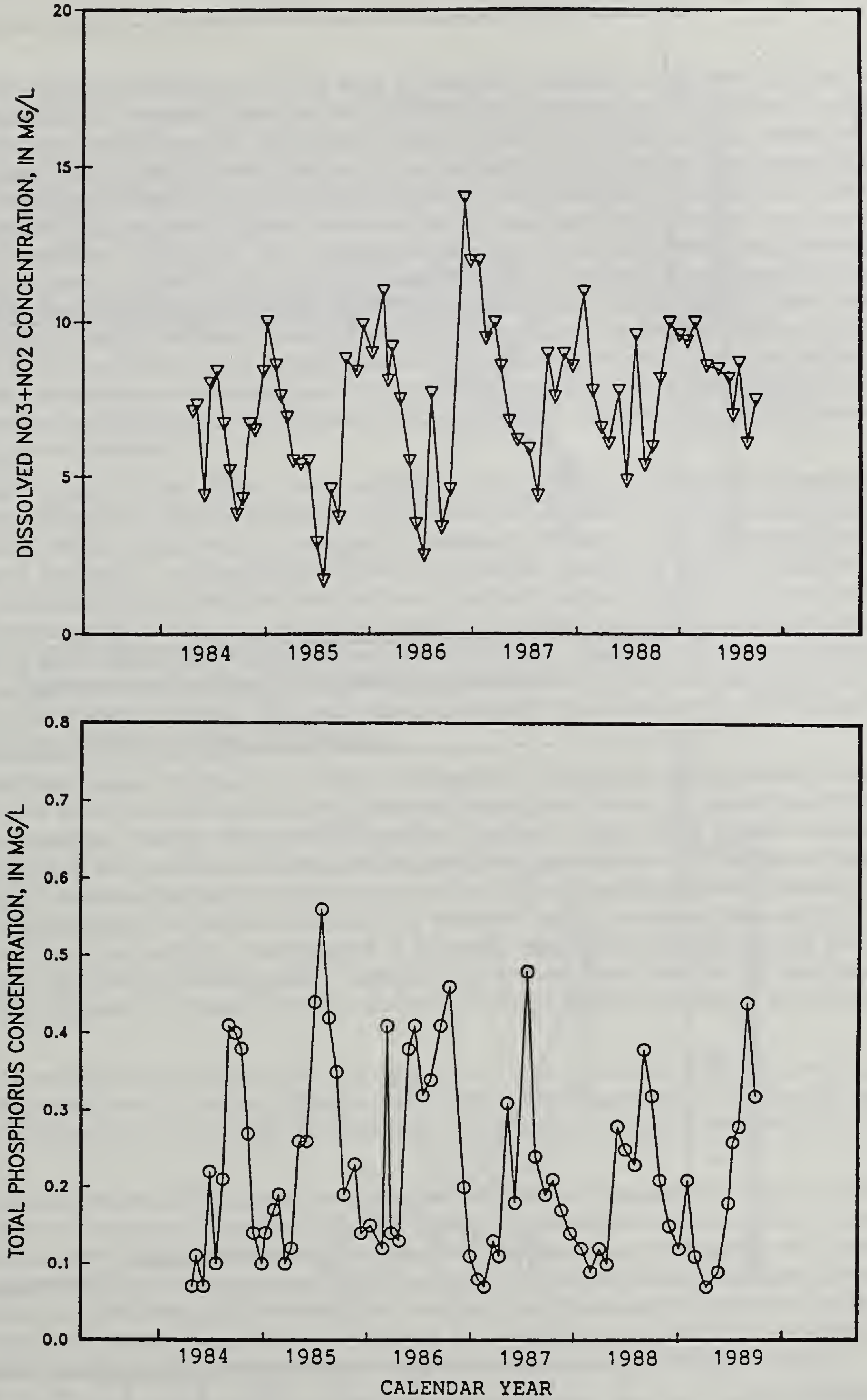
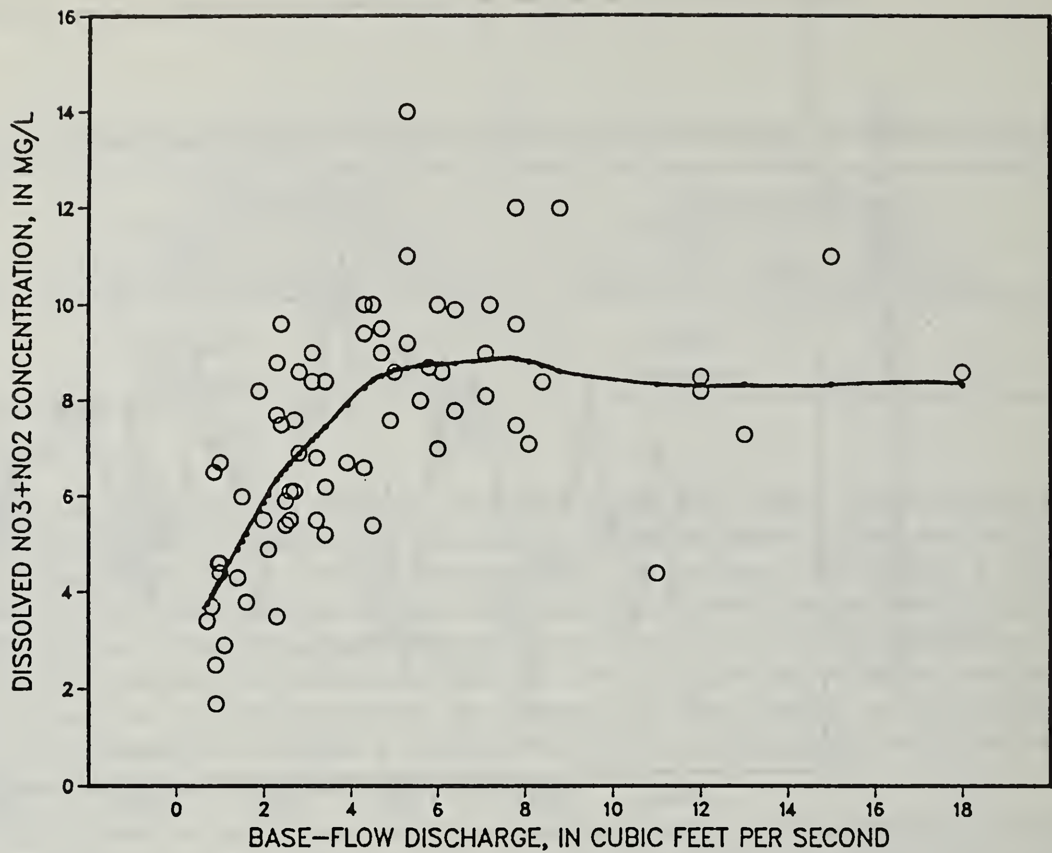


Figure 7.3-11.-- Time series of base-flow dissolved nitrate plus nitrite and total phosphorus concentrations at Station 5, April 1984 through October 1989.



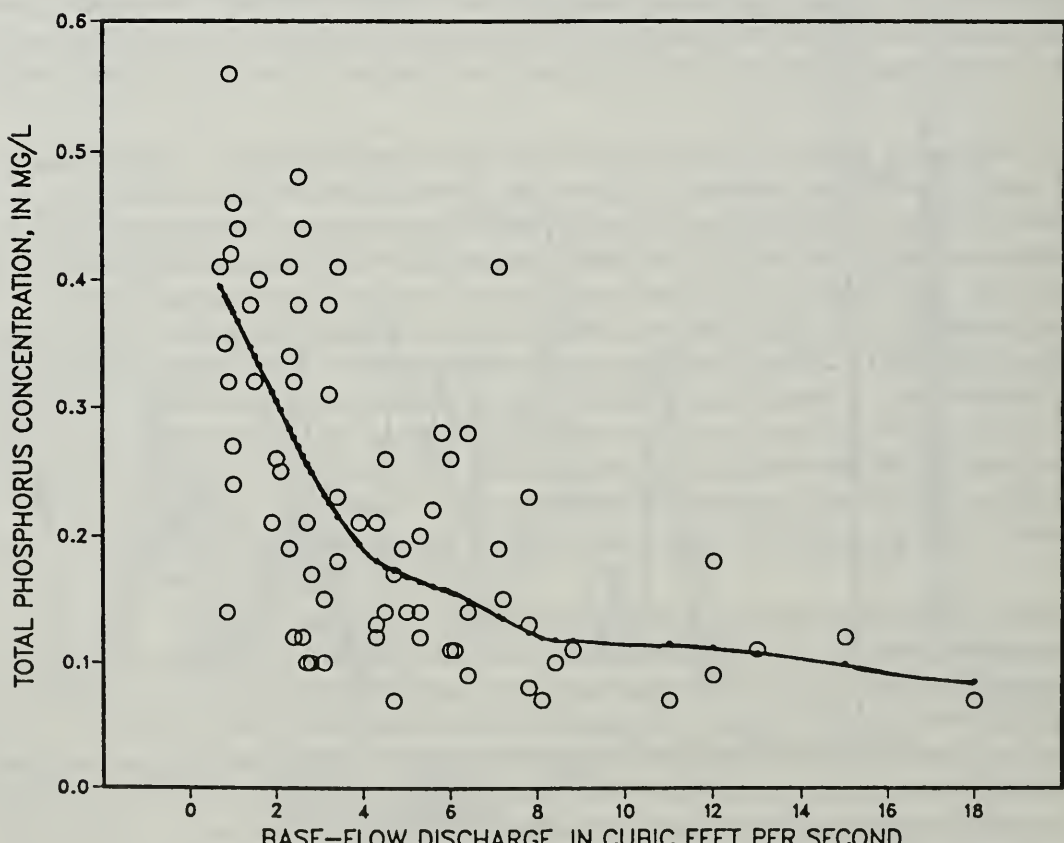


Figure 7.3-12.--Relation between dissolved nitrate plus nitrite and discharge and between total phosphorus and discharge in base flow at Station 5, April 1984 through September 1989.

A seasonally corrected Rank-Sum test was used to determine whether a step trend had occurred in median concentrations of nutrients between the pre-BMP and post-BMP periods. Prior to testing for changes in nutrient concentrations, the first year of post-BMP data (April 1986 through March 1987) was deleted from the data set for the following reasons: (1) not all farms in the Nutrient-Management subbasin received their nutrient-management plans exactly at the start of the post-BMP period, and (2) a minimum, although undetermined, time period elapses before infiltrating waters and the nutrients they transport are discharged as base-flow. Results of the seasonal Rank-Sum test for observed and flow-adjusted concentrations are listed in table 7.3-10. Few significant changes in median concentrations of nutrients occurred between the pre-BMP to post-BMP period for the observed or flow adjusted data. Dissolved ammonia at Stations 1 and 4 and total ammonia plus organic nitrogen at Station 5 showed significant decreases of 0.10, 0.03, and 0.28 mg/L, respectively. These decreases account for 3 percent or less of the median base-flow total-nitrogen concentration. For the observed data at Station 5, a significant decrease of 0.02 mg/L was seen in the median concentration of total phosphorus. However, after flow adjustment no significant change was detected.

Water-quality goals for the project were established by defining maximum concentrations for acceptable water-quality at the start of the Conestoga Headwaters project (U.S. Department of Agriculture, 1984). The goal for nitrate was 10 mg/L as nitrogen; for ammonia nitrogen, 1.5 mg/L as nitrogen; and for total phosphorus, 0.03 mg/L as phosphorus. Table 7.3-11 lists the percent of base-flow samples which exceeded the established goals during the pre-BMP and post-BMP periods. Dissolved-nitrate plus nitrite concentrations exceeded the 10 mg/L goal more often in the post-BMP period at Stations 5 and 4 and less often at Station 3, which drains the Nutrient-Management Subbasin. Dissolved-ammonia concentrations exceeded the goal once at Station 5 only in the pre-BMP period but did not exceed the goal at any of the stations during the post-BMP period. The total phosphorus goal was exceeded by all of the base-flow samples during the pre-BMP and post-BMP periods.

In summary, after implementation of nutrient management, no statistically significant change was detected in median base-flow concentrations of dissolved nitrate plus nitrite, the primary source of base-flow nitrogen. However, during the post-BMP period dissolved nitrate plus nitrite concentrations exceeding the 10 mg/L as N criterion occurred less frequently in discharge from the Nutrient-Management Subbasin (Station 3) and more frequently in discharge from the Nonnutrient Management Subbasin (Station 4) and from the entire Small Watershed (Station 5). The reduction in the percentage of samples exceeding the criterion suggests that nutrient management is affecting maximum dissolved nitrate plus nitrite concentrations in the Nutrient-Management Subbasin. No trends were detected in base-flow total-phosphorus concentrations, and base-flow concentrations of total phosphorus exceeded the criterion at all stations.

Stormflow samples from 55 percent of the 164 storm events which occurred at Station 3 and 62 percent of the 171 storm events which occurred at Station 5 were analyzed for nutrients and suspended sediment or suspended sediment only. An average of 7 sediment and 8 nutrient samples were analyzed for each storm event.

Sample analyses showed that suspended-sediment and nutrient concentrations varied during the course of a storm in response to storm discharge. Typically, suspended-sediment, total organic plus ammonia-nitrogen, and total-phosphorus concentrations increased and decreased with discharge. Maximum concentrations of these constituents occurred from at to slightly before maximum discharge. In contrast, nitrate plus nitrite nitrogen concentrations increased and decreased in opposition to discharge. Minimum nitrate plus nitrite concentrations occurred at to slightly after maximum discharge while maximum nitrate plus nitrite concentrations occurred at the beginning or end of a storm event.

Maximum storm concentrations of total organic plus ammonia nitrogen, total phosphorus and suspended sediment typically occurred in spring and early summer. Maximum total organic plus ammonia-nitrogen concentrations were measured in July at Station 3 and June at Station 5 (37 mg/L and 35 mg/L respectively). Maximum suspended sediment and total phosphorus concentrations were measured in May at both stations (16,700 mg/L of suspended sediment and 24 mg/L of total phosphorus at Station 3 and 34,300 mg/L of suspended sediment and 17 mg/L of total phosphorus at Station 5). The

Table 7.3-10.--Step trends between pre-BMP (April 1984 through March 1986) and post-BMP (April 1987 through September 1989) observed and flow-adjusted base flow nutrient concentrations in the Small Watershed detected using the seasonal Rank-Sum test

[--, no flow dependency]

		Observed data		Flow-adjusted data	
Station	Parameter	Step trend	Probability (P)	Step trend	Probability (P)
1	Streamflow	0.05	0.45	--	--
	Dissolved $NO_3 + NO_2$-N	-.10	.21	-0.22	0.21
	Dissolved NH_3 - N	-.10	<.01*	--	--
	Total NH_3 + Organic - N	-.08	.13	--	--
	Total phosphorus	<-.01	.35	<-.01	.83
2	Streamflow	--	--	--	--
	Dissolved $NO_3 + NO_2$-N	.00	.90	-.25	.41
	Dissolved NH_3 - N	-.10	.64	--	--
	Total NH_3 + Organic - N	-.15	.19	--	--
	Total phosphorus	-.04	.11	-.03	.39
3	Streamflow	.16	.20	--	--
	Dissolved $NO_3 + NO_2$-N	-.78	.20	-.50	.20
	Dissolved NH_3 - N	-.03	.09	--	--
	Total NH_3 + Organic - N	-.19	.30	--	--
	Total phosphorus	-.01	.28	<.01	.83
4	Streamflow	.06	.61	--	--
	Dissolved $NO_3 + NO_2$-N	.40	.36	.37	.30
	Dissolved NH_3 - N	-.03	.01*	--	--
	Total NH_3 + Organic - N	-.22	.15	--	--
	Total phosphorus	-.02	.90	-.03	.16
5	Streamflow	.65	.32	--	--
	Dissolved $NO_3 + NO_2$-N	.80	.31	.69	.06
	Dissolved NH_3 - N	-.04	.17	--	--
	Total NH_3 + Organic - N	-.28	.01*	--	--
	Total phosphorus	-.02	.02*	<.01	.76

* Significant at the 95 percent confidence level.

greater sediment concentrations that occur in the Spring are probably influenced by two factors. First, pre-planting tillage of cropland increases the supply of easily erodible sediment and second, increased grazing activity can damage stream banks which have been destabilized due to over-winter vegetation die-back and frost. Because phosphorus is known to bind to soil particles, it is likely these same factors are also the primary cause of the larger phosphorus concentrations.

Monthly nitrogen, phosphorus and suspended sediment loads for Station 3, the Nutrient-Management Subbasin, and Station 5, the Small Watershed, are shown in figures 7.3-13 and 7.3-14. Pre-BMP to post-BMP comparison showed no significant change in nitrogen loads at either station. At both stations, nitrate plus nitrite typically comprised the majority of the monthly nitrogen load. The median percentage of monthly nitrogen load that was nitrate plus nitrite was 83 percent at Station 3 and 67 percent at Station 5. Figure 7.3-14 shows that during the post-BMP period ammonia plus organic nitrogen comprised a larger proportion of the monthly load during months with the largest loads. Monthly loads of total phosphorus

Table 7.3-11.--Base-flow samples exceeding water-quality criteria established for the Conestoga Headwaters RCWP

[Sample numbers are listed in percent greater than criterion]

Station	Dissolved nitrate plus nitrite[1]		Dissolved ammonia[2]		Total phosphorus[3]	
	Pre-BMP	Post-BMP	Pre-BMP	Post-BMP	Pre-BMP	Post-BMP
1	0	0	0	0	87	86
2	0	0	0	0	100	100
3	3.6	2.5	0	0	100	100
4	0	4.8	0	0	100	100
5	3.3	9.5	3.3	0	100	100

[1] Criterion for dissolved nitrate plus nitrite is 10 milligrams per liter as nitrogen.

[2] Criterion for dissolved ammonia is 1.5 milligrams per liter as nitrogen.

[3] Criterion for total phosphorus is 0.03 milligrams per liter as phosphorus.

and suspended sediment at Stations 3 and 5 had lower maximums during the first year of the post-BMP period when compared to the pre-BMP period. However during the remainder of the post-BMP period significant increases in total phosphorus loads were detected at Station 5 and significant increases in the sediment load were detected at Station 3. These increases were primarily a result of increases in monthly discharges. Because loads are the product of streamflow and concentration, variation in either will cause a change in the load. At Stations 3 and 5 streamflow had the greater variation and therefore the greatest effect on the loads. When pre-BMP and post-BMP discharge-weighted monthly loads were compared, no significant change was detected in total nitrogen, dissolved nitrate plus nitrite, total ammonia plus organic nitrogen, total phosphorus, or suspended sediment at either Station 3 or 5.

Nutrient and sediment loads were not transported proportionally by the base flow and stormflow components of discharge. Most of the nitrogen was discharge in base-flow, whereas most of the phosphorus and suspended sediment was discharged in storm flow except for suspended sediment at Station 3 (fig. 7.3-15). No significant pre-BMP to post-BMP period change in the proportioning of these constituents loads was detected using the Wilcoxon rank-sum test.

A summary of annual nitrogen, phosphorus, and suspended-sediment loads for Stations 3 and 5 is listed in table 7.3-12. At Station 3, post-BMP total nitrogen loads were consistently lower than pre-BMP annual total-nitrogen loads. Most of the reduction occurred in nitrate plus nitrite loads. Annual total-phosphorus and suspended-sediment loads were not consistently lower in the post-BMP period. In contrast, at Station 5 post-BMP annual total-nitrogen loads were greater for all but the first post-BMP year. Total-phosphorus and suspended-sediment loads at Station 5 behaved similarly. Notably, loads at Station 5 for the final 6 months of the post-BMP period exceeded annual loads of both pre-BMP years.

The effects of nutrient management on surface-water quality in the Small Watershed was evaluated using both a qualitative and quantitative approach. Doing so qualitatively requires, in the simplest sense, only that changes in water-quality be coincident with changes in agricultural activities due to nutrient management. Doing so quantitatively has the advantage of identifying a specific water-quality response to agricultural activity changes but is more complex. This complexity results from the need to separate all non-BMP influences on water-quality from BMP influences and to develop a statistically and functionally sound relation between agricultural activities and water-quality.

Qualitative evaluation was accomplished by comparison of pre-BMP and post-BMP water-quality data. The pre-BMP to post-BMP evaluation of base-flow water-quality for the entire watershed was qualitative because agricultural-activity data was not collected throughout the watershed and therefore actual BMP

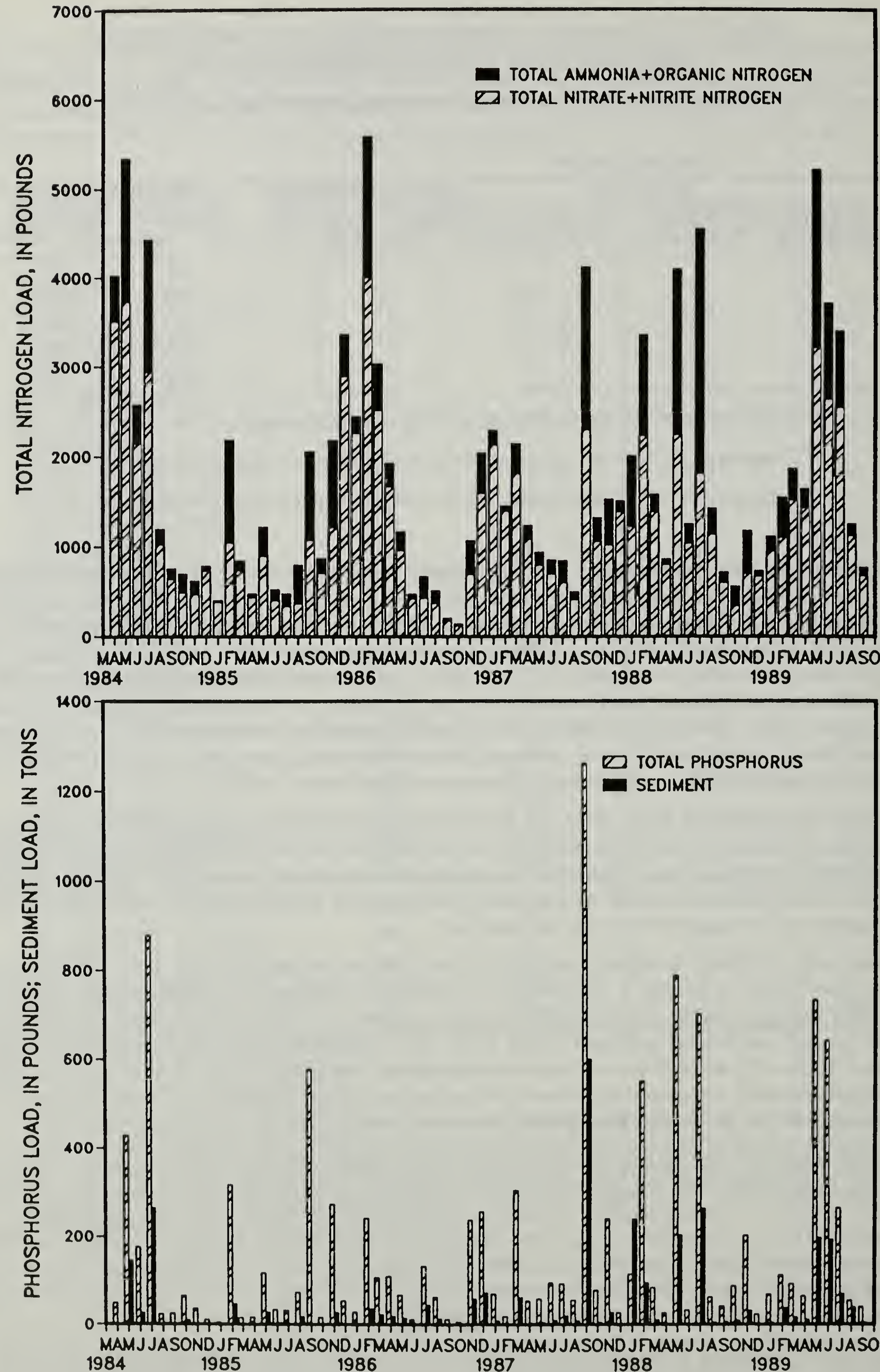
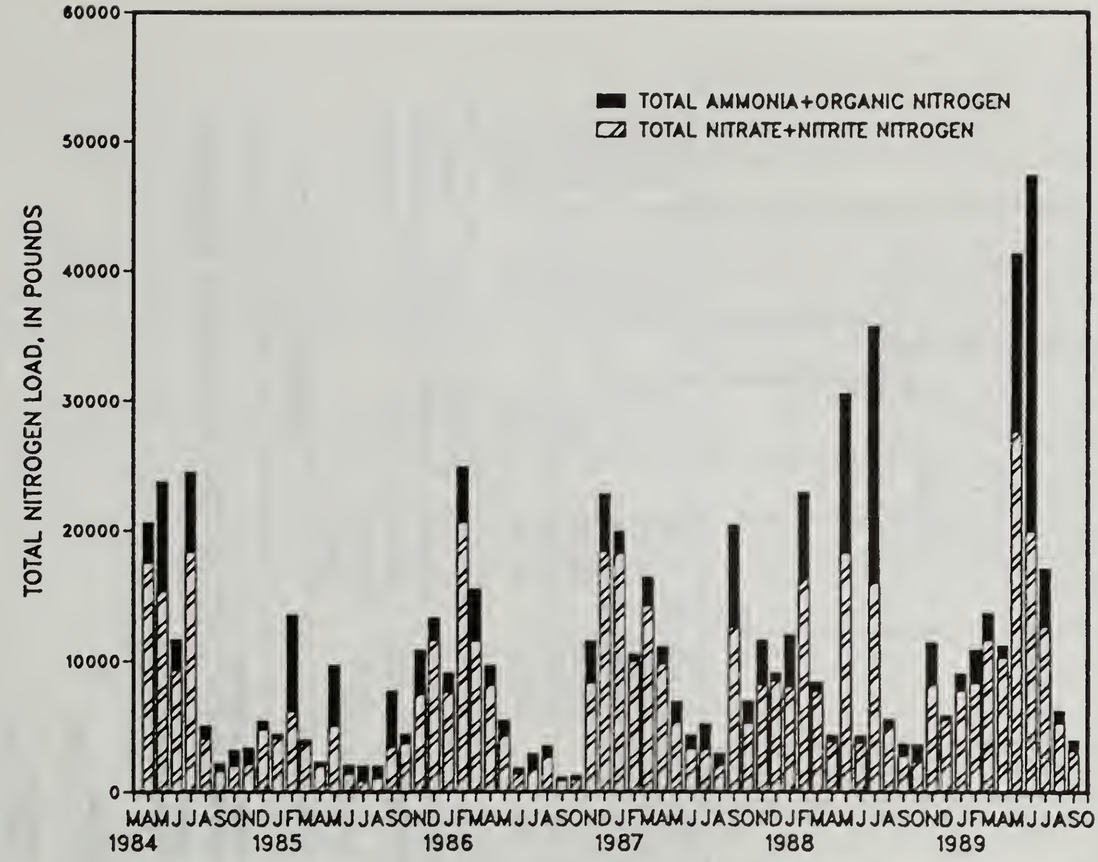


Figure 7.3-13.-- Monthly loads of nitrogen as N (above) and total phosphorus as P and suspended sediment (below) at Station 3.



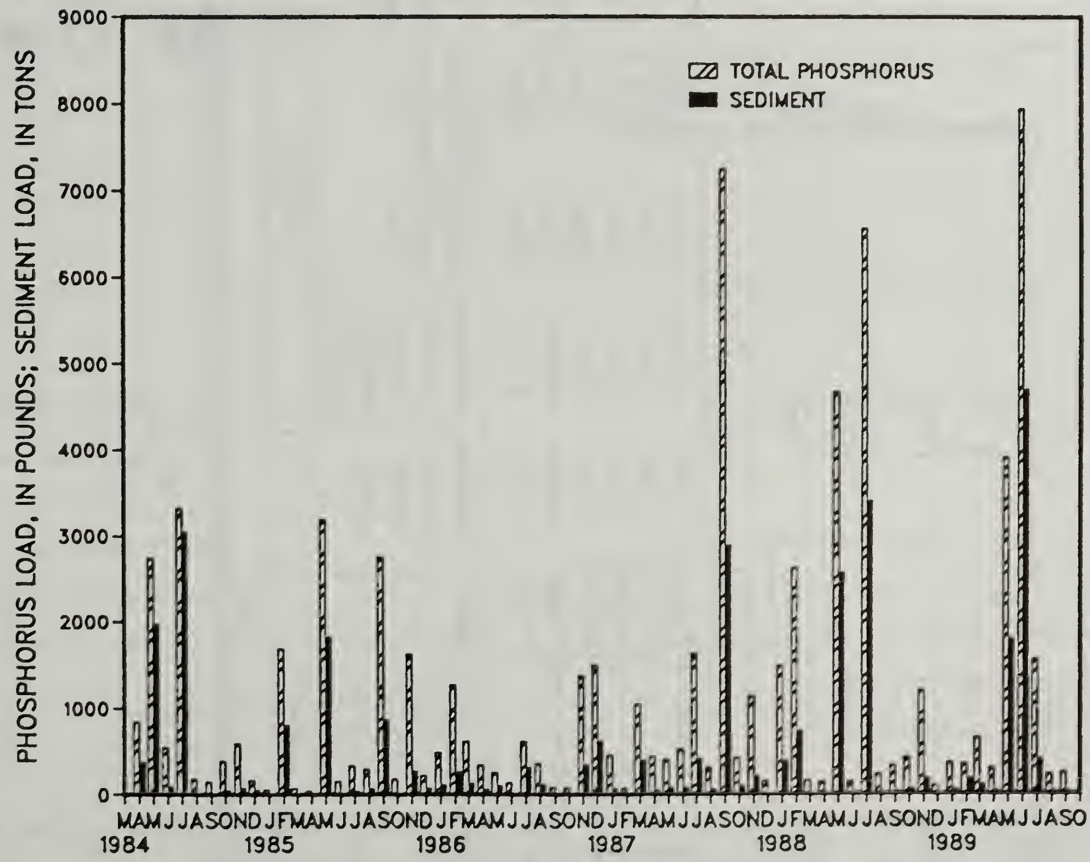


Figure 7.3-14.-- Monthly loads of nitrogen as N (above) and total phosphorus as P and suspended sediment (below) at Station 5.

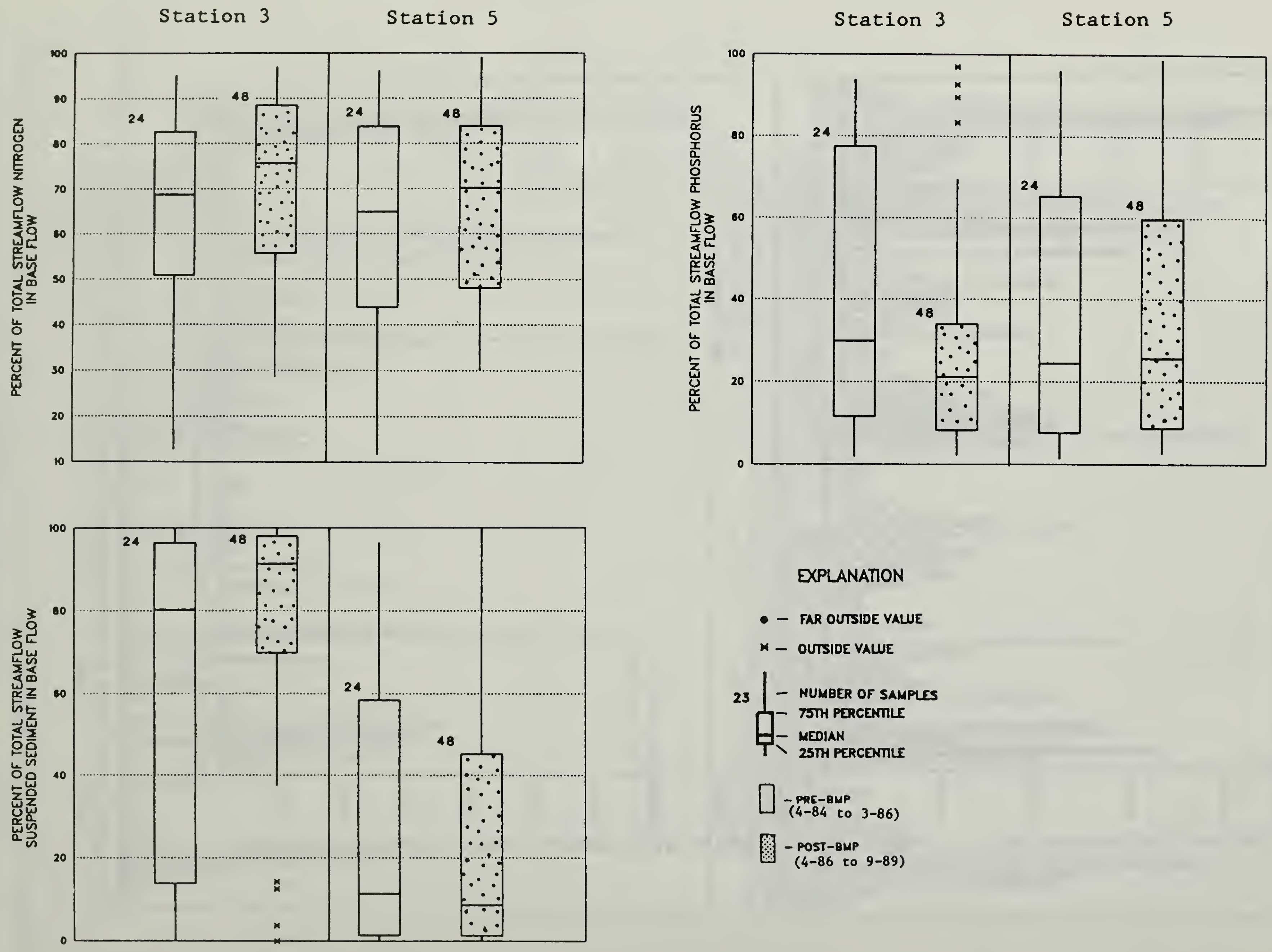


Figure 7.3-15.--Base flow contribution of nutrients and suspended sediment to total streamflow load at Stations 3 and 5.

Table 7.3-12.--Annual nitrogen, phosphorus, and suspended-sediment loads for Station 3 and Station 5 in the Small Watershed

Year	Period	Station 3					Station 5				
		Total nitrate + nitrite (pounds)	Total ammonia + organic nitrogen (pounds)	Total nitrogen (pounds)	Total phosphorus (pounds)	Suspended sediment (tons)	Total nitrate + nitrite (pounds)	Total ammonia + organic nitrogen (pounds)	Total nitrogen (pounds)	Total phosphorus (pounds)	Suspended sediment (tons)
April 1984 - March 1985	Pre-BMP	17,800	6,000	23,800	2,030	510	88,800	33,100	121,900	10,700	6,520
April 1985 - March 1986	Pre-BMP	17,000	6,000	23,000	1,570	150	76,100	27,800	103,900	11,200	3,720
April 1986 - March 1987	Post-BMP	11,700	2,300	14,000	1,290	300	88,900	18,100	107,000	6,300	2,060
April 1987 - March 1988	Post-BMP	14,100	5,700	19,800	2,710	1,000	90,200	32,000	122,200	16,600	5,030
April 1988 - March 1989	Post-BMP	12,900	7,000	19,900	2,240	590	93,700	45,800	139,500	15,200	6,700
April 1989 - September 1989[1]	Post-BMP	11,600	4,400	16,000	1,800	520	79,200	48,600	127,800	14,200	7,000

[1] Loads are for 6-month period.

changes, such as reductions in nutrient applications, were not known. As discussed earlier in this section, nutrient management, to the degree it was implemented in the watershed as a whole, resulted in no detectable change in median base-flow nitrogen concentrations and a minimal reduction in median base-flow total phosphorus concentrations in surface-water discharge from the watershed.

Due to the large influence of seasonal, climatic, and other non-BMP factors, it would be difficult using strictly a pre-post comparison to conclude that any changes detected in water quality were caused by nutrient management. Because pairing cancels much of the non-BMP influences common to both subbasins, a paired-subbasin experiment was added in a portion of the watershed to improve the ability to detect water-quality changes.

A paired-watershed comparison of base-flow nutrient concentrations was made using double-mass plots and analysis of covariance. An assumption in the paired watershed comparison was that the hydrologic relation between the Nutrient-Management Subbasin and the Nonnutrient-Management Subbasin was constant, that is the base-flow discharge ratio is constant. Under this assumption a plot of cumulative flux values will have a constant slope as long as the concentration relation is also constant. Flux is defined as base-flow concentration multiplied by base-flow discharge. Therefore, a break in the slope indicates a change in the concentration relation between the subbasins. Figures 7.3-16 and 7.3-17 are double-mass plots showing cumulative flux values for nitrate plus nitrite and total phosphorus from the Nutrient-Management Subbasin compared to values from the Nonnutrient-Management Subbasin. As figure 7.3-16 shows, the dissolved nitrate plus nitrite flux from the Nutrient-Management Subbasin was reduced relative to the Nonnutrient-Management Subbasin but total phosphorus flux was increased. However, for unknown reasons, an increase in discharge from between the subbasins coincident with the changes in the flux relations violated the assumption of a constant hydrologic relation between the subbasins (fig. 7.3-18). This change in the discharge relation caused a greater total phosphorus flux change than actually existed and reduced the apparent decrease in nitrate plus nitrite flux. Analysis of covariance detected significant pre-BMP to post-BMP changes in median base-flow nitrate plus nitrite concentrations when the paired subbasin were compared (fig. 7.3-19). Although not statistically significant by themselves, decreasing median concentrations in the Nutrient-Management Subbasin and increasing median concentrations in the Nonnutrient-Management Subbasin (table 7.3-10) combined to result in a significant change in the base-flow nitrate plus nitrite relation between the subbasins. Decreases in concentrations from the Nutrient-Management Subbasin accounted for most of the change. Analysis of covariance detected no significant change in total phosphorus concentrations between subbasins (fig. 7.3-20).

A quantitative evaluation required that comprehensive water-quality and agricultural activity data be collected over the study period. Because collection of agricultural-activity data was restricted to the 1.4-mi^2 Nutrient-Management Subbasin quantitative evaluation of the relation between water-quality and agricultural activity was limited to this subbasin.

Quantitative evaluation was done with regression procedures. Various combinations of nutrient application quantity, precipitation quantity, streamflow, and season were explored as explanatory factors of base-flow nutrient concentrations. None of the combinations were found to be significant explanatory factors. This result was not unexpected; irregular recharge intervals and quantities, nonuniform groundwater-transit times and distances all contributed to masking any correlation between nutrient applications and base-flow nutrient concentrations.

The results from pesticide samplings at Stations 1, 3, and 5 are shown in table 7.3-13. Pesticides were detected in 18 percent of the samples collected at Station 1. Land-use information from field reconnaissance of an area upstream from Station 1 revealed that many used pesticide containers were scattered throughout the wooded area. The containers were removed from the area after the first year of the study. Pesticides were consistently present at Stations 3 and 5. Seventy-one percent of the 34 base flow samples and 86 percent of the 21 storm samples collected at Station 3 contained pesticides. At Station 5, 83 percent of the 46 base flow samples and 88 percent of the 52 storm samples collected contained pesticides. Atrazine was the pesticide most frequently detected at Stations 3 and 5. Over 60 percent of the base flow and storm samples at Station 3, and over 70 percent of the base flow and storm samples at Station 5 contained detectable concentrations of atrazine. Maximum monthly concentrations of total atrazine at Stations 3 and 5 generally occurred

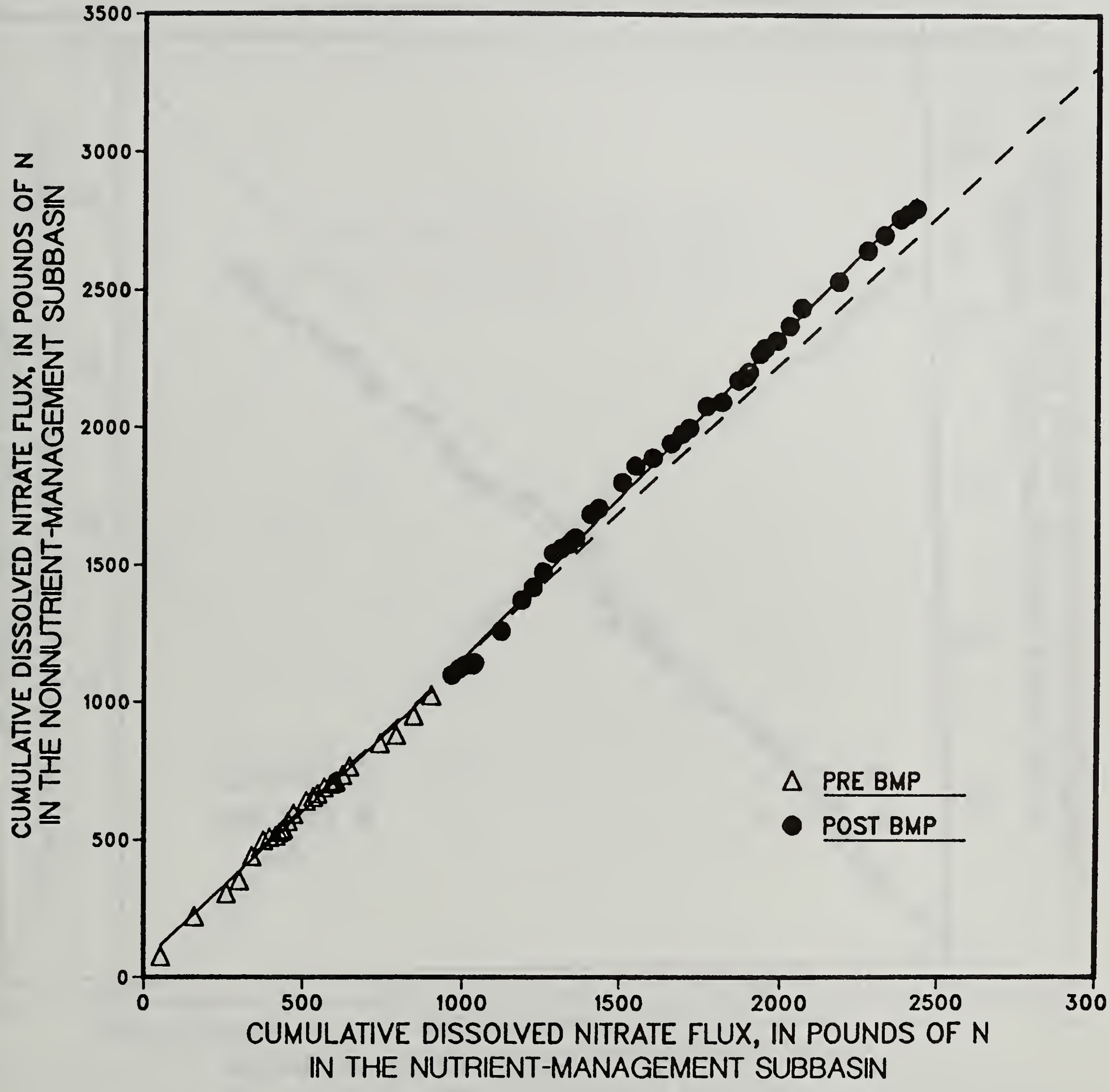


Figure 7.3-16.-- Comparison of cumulative base-flow dissolved nitrate flux for the Nutrient-Management and Nonnutrient-Management subbasins during the pre-BMP (April 1984 through March 1986) and post-BMP (April 1986 through September 1989) study periods.

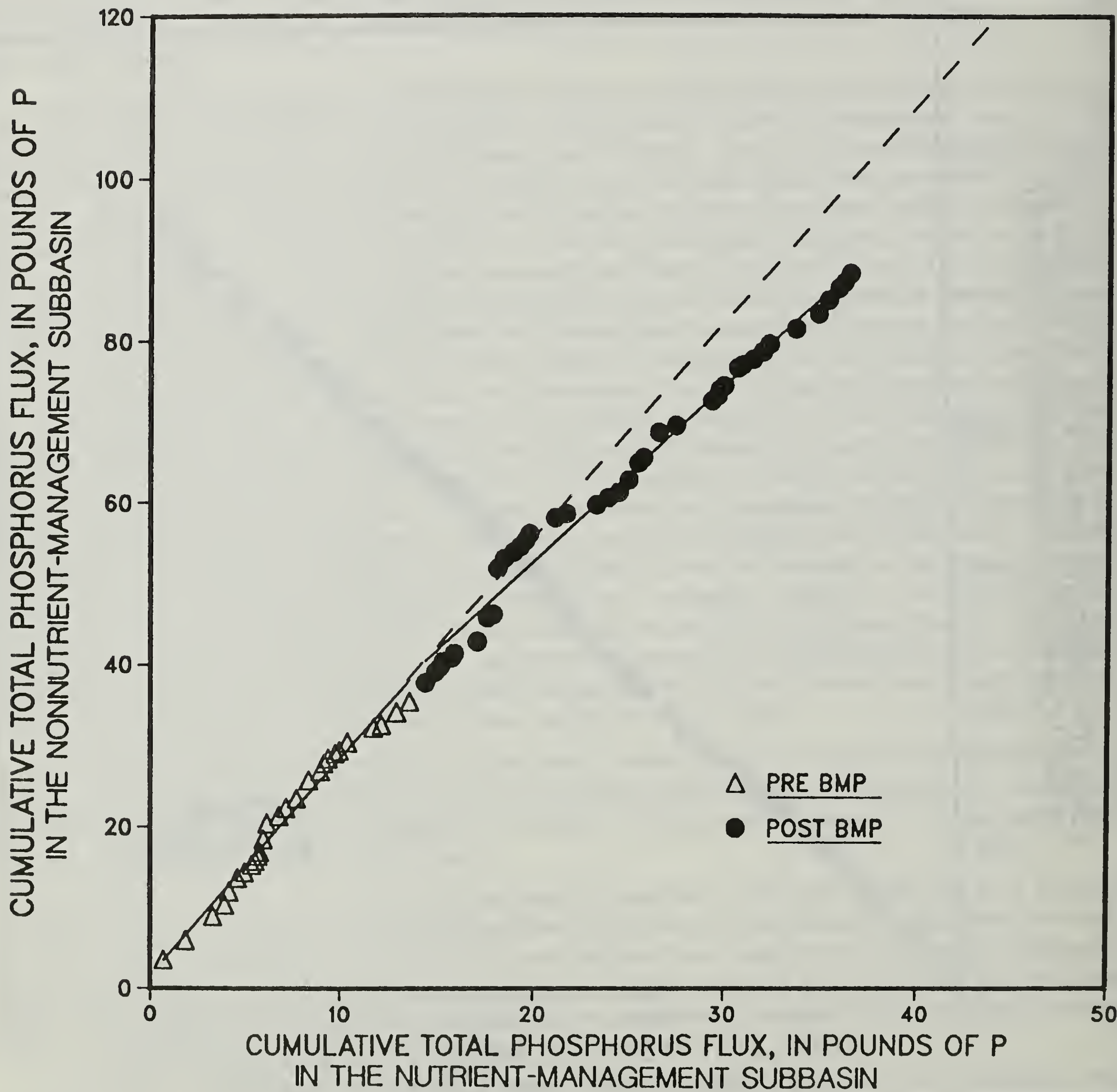


Figure 7.3-17.-- Comparison of cumulative base-flow total phosphorus flux for the Nutrient-Management and Nonnutrient-Management subbasins during the pre-BMP (April 1984 through March 1986) and post-BMP (April 1986 through September 1989) study periods.

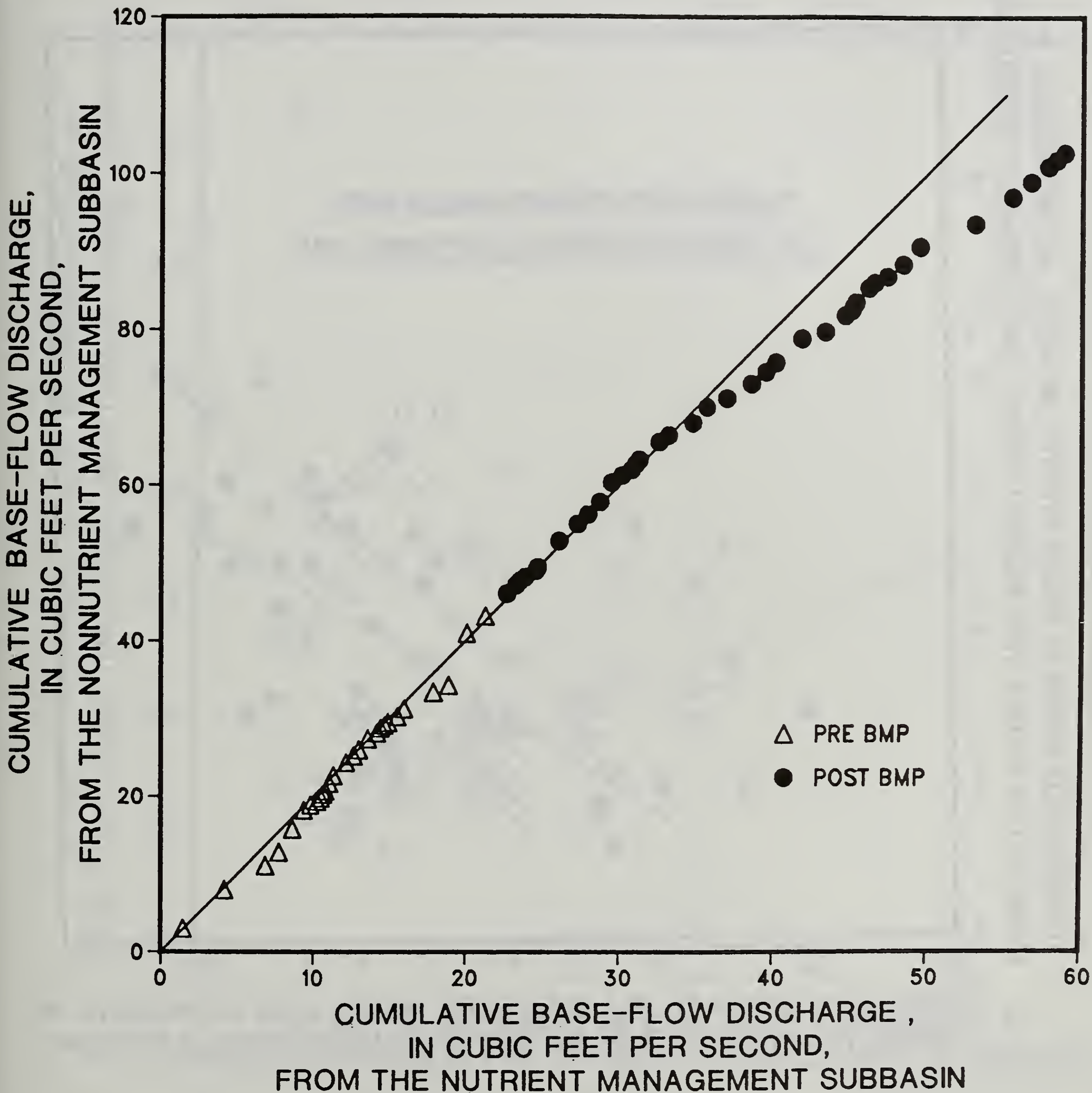


Figure 7.3-18.-- Comparison of cumulative base-flow discharge for the Nutrient-Management and Nonnutrient-Management subbasins during the pre-BMP (April 1984 through March 1986) and post-BMP (April 1986 through September 1989) study periods.

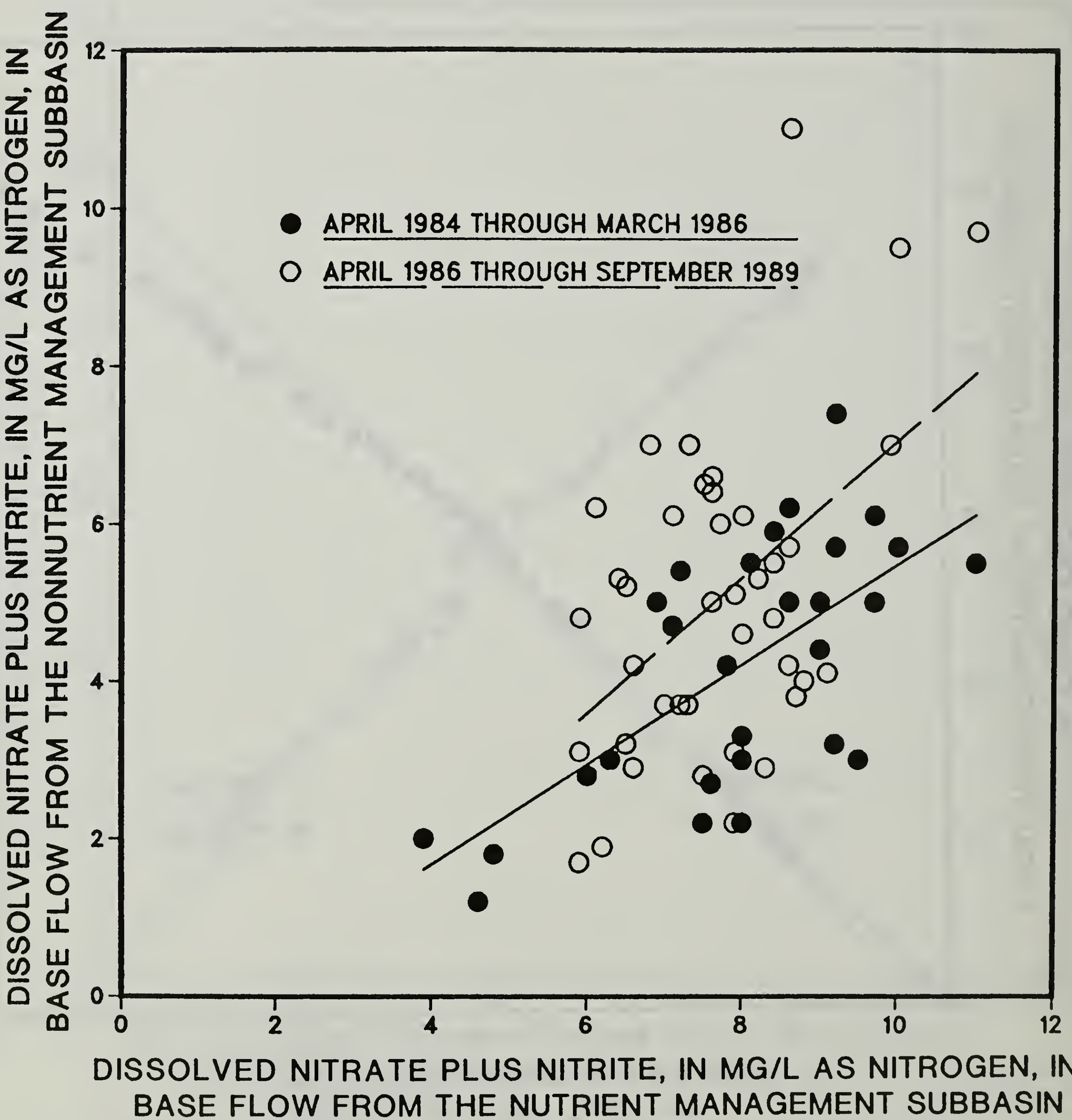


Figure 7.3-19.-- Relation between base-flow nitrate plus nitrite nitrogen concentrations from the Nutrient-Management and Nonnutrient-Management subbasins.

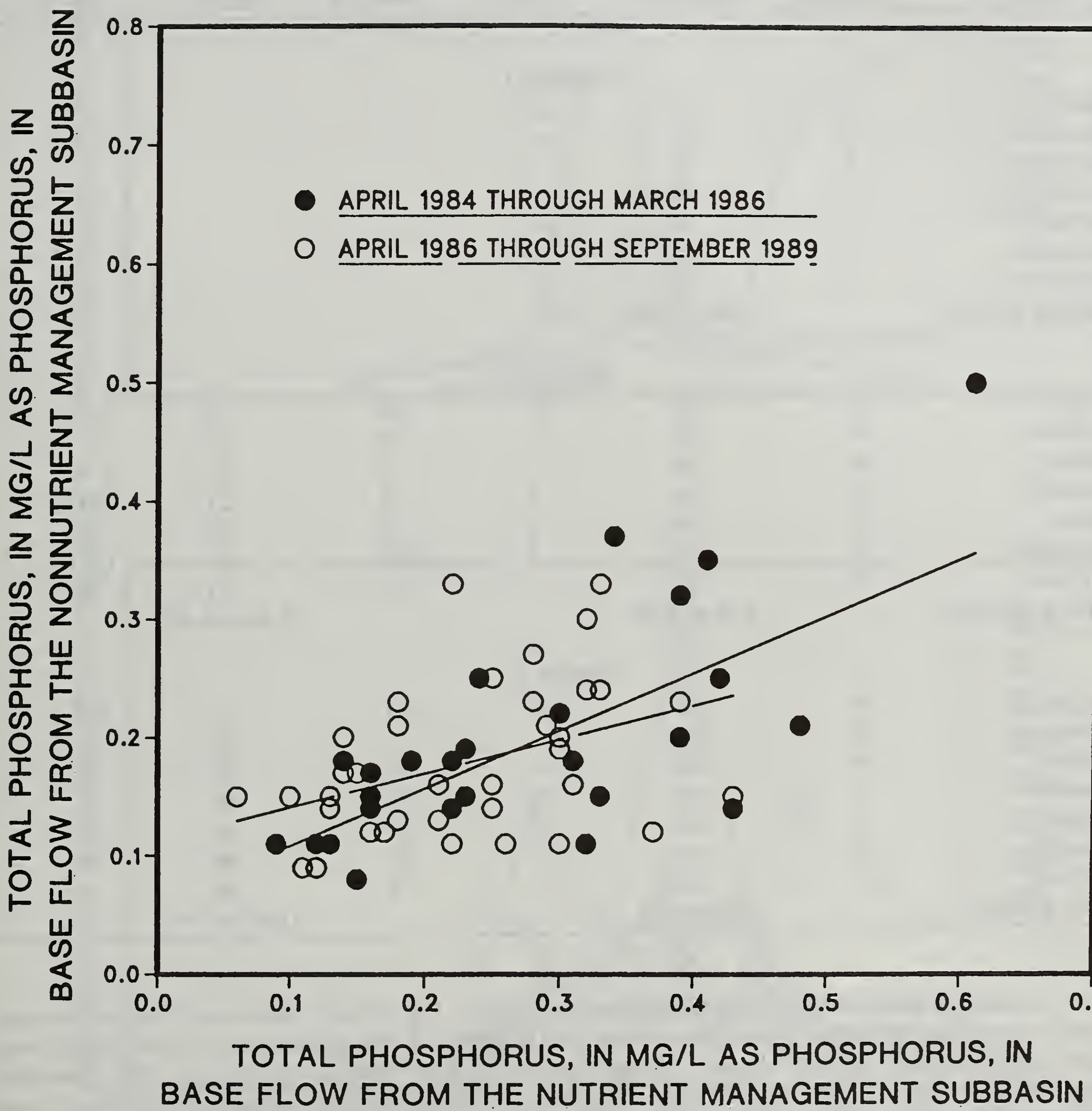


Figure 7.3-20.-- Relation between base-flow total phosphorus concentrations from the Nutrient-Management and Nonnutrient-Management subbasins.

Table 7.3-13.--Pesticide concentrations in samples from the Small Watershed Study Area

[µg/L, micrograms per liter; --, none detected]

Pesticide	Base flow: No. of times detected	Base flow: No. of analyses	Base flow: Maximum concentration (µg/L)	Stormflow: No. of times detected	Stormflow: No. of analyses	Stormflow: Maximum concentration (µg/L)
			Station 1			
Atrazine	2	37	0.4			
Propazine	0	37	--			
Simazine	5	37	.7			
Cyanazine	0	37	--			
Alachlor	0	38	--			
Metolachlor	2	38	.2			
Toxaphene	0	36	--			
Sampling period		10-83 to 9-89				
			Station 3			
Atrazine	21	34	2.7	14	21	210
Propazine	0	34	--	0	21	--
Simazine	10	34	.8	7	21	14
Cyanazine	10	34	.9	9	21	200
Alachlor	4	35	.1	6	21	56
Metolachlor	13	35	.4	15	21	250
Toxaphene	0	33	--	1	21	20
Sampling period		3-84 to 9-89			5-84 to 6-87	
			Station 5			
Atrazine	34	46	2.6	40	52	120
Propazine	0	46	--	1	52	13
Simazine	19	46	1.3	20	52	21
Cyanazine	6	46	.8	21	52	72
Alachlor	2	40	.1	24	48	85
Metolachlor	12	40	.9	15	48	75
Toxaphene	0	38	--	0	48	--
Sampling period		5-82 to 9-89			11-82 to 9-87	

within 3 months of the spring-planting application of atrazine (fig. 7.3-21). Maximum concentrations of atrazine in base flow at Stations 3 and 5 were measured in 1989 and 1987, respectively. Unlike other years, atrazine concentrations in 1989 showed multiple peaks at both stations. Except for 1989, base-flow concentrations at Station 5 were slightly larger than base-flow concentrations at Station 3. Although base-flow concentrations of atrazine were generally near the detection limit by October, low concentrations were sometimes detected into December.

7.3.5 Small Watershed Ground-Water Quality

Ground water was sampled from six wells and two springs (fig. 6-3)(table 6-8) about 3 times per year in the Nutrient-Management Subbasin. The ground water at each of the sites is used for domestic and agricultural purposes. The data from the samplings wells and springs was used to characterize ground-

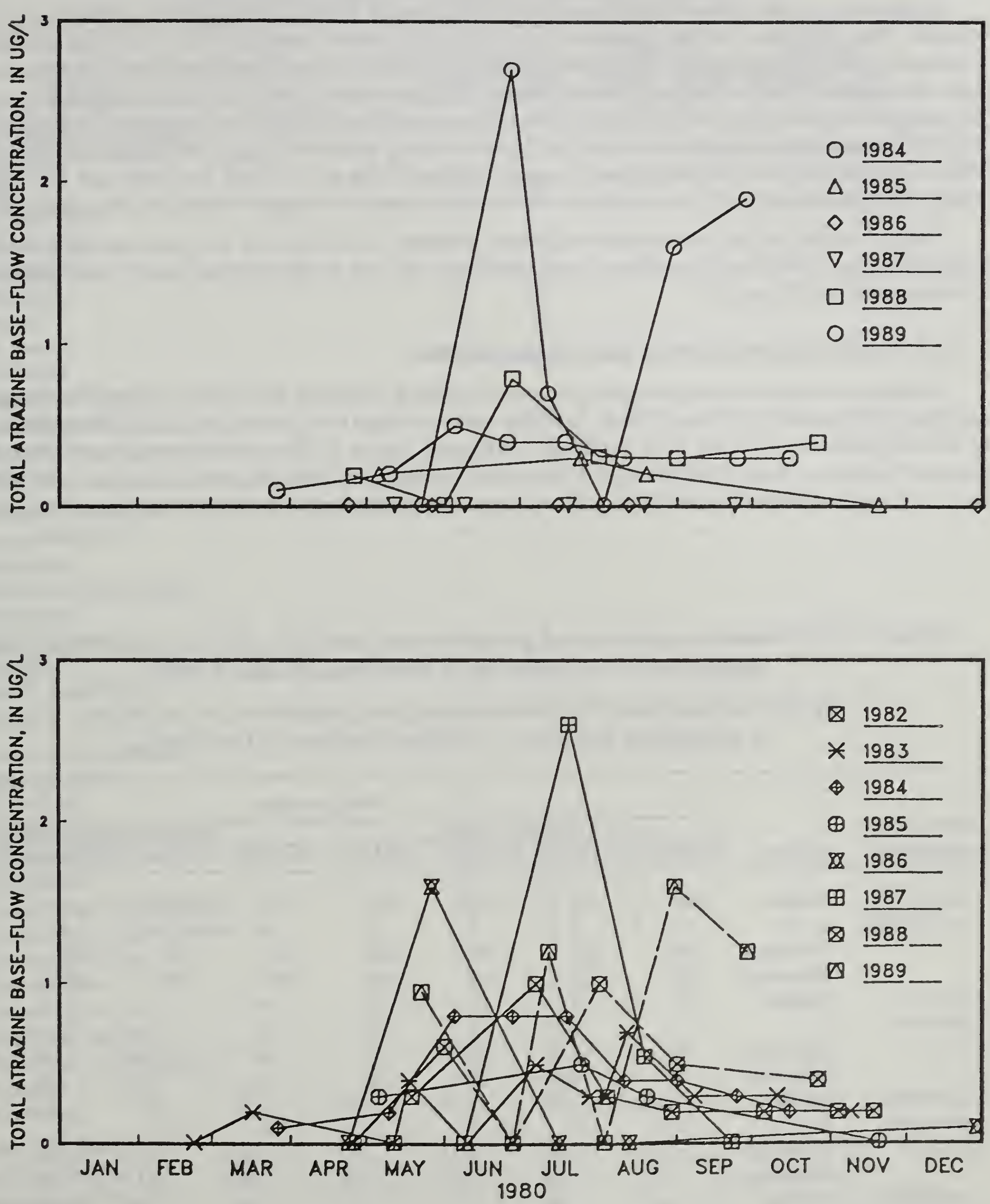


Figure 7.3-21.-- Total atrazine concentrations in base-flow samples from Station 3 (above) and Station 5 (below).

water quality. However due to location and usage of many of the wells, the data probably represents highly localized conditions. Because of the uncertainty in the data, sampling was discontinued in 1987.

A summary of the data collected from April 1984 through March 1986 is listed in table 7.3-14. The data indicate that dissolved-nitrate concentrations in ground-water samples from the intensively-farmed carbonate valley were generally larger and had greater variation than those from the sandstone and shale area. The highest dissolved-nitrate concentrations were measured at well LN 1663 in the carbonate valley. All samples collected from wells located in the carbonate valley, LN SP59, LN 1663, and LN 1678, exceeded the USEPA maximum contaminant level (MCL) for drinking water of 10 mg/L for nitrate nitrogen (USEPA, 1990). Dissolved-nitrate concentrations changed relatively little at LN 1665, LN 1662, and LN 1666, all of which are representative of ground water in the sandstone and shale region rather than the carbonate valley.

Ground water in the Nutrient-Management Subbasin has relatively low and constant phosphorus concentrations. Dissolved-phosphorus concentrations for all of the ground-water sites ranged from nondetectable to 0.07 mg/L.

7.3.6 Small Watershed Benthic Macroinvertebrates

Benthic macroinvertebrate samples and corresponding chemical data were collected in October 1988 and May 1989 (tables 7.3-15 and 7.3-16). Samples were analyzed using methods described in section 6.7.6.6, at 3 sites, Stations 1, 3, and 4, in the Small Watershed (fig. 6-2). The macroinvertebrate community at Station 1 was very diverse in 1989 with 32 total taxa versus 15 in 1988. Mayflies, stoneflies, and caddisflies were well represented at the site along with midges and elmids. Station 1 was least impacted by agriculture.

Table 7.3-14.--Summary statistics of ground-water quality in the Nutrient-Management Subbasin for the period April 1984 through March 1986

[Specific conductance, in microsiemens per centimeter; concentration, in milligrams per liter; n, number of values; <, less than]

Characteristic or constituent	Statistic	Well or spring: Carbonate valley: LN SP59	LN 1586	LN 1663	LN 1678	Sandstone and shale area: LN SP60	LN 1662	LN 1665	LN 1666
Specific conductance	Median	603	645	705	680	162	445	400	594
	n	7	7	7	3	4	7	7	6
	Minimum	570	555	595	672	159	417	382	385
	Maximum	730	775	735	795	185	532	497	785
Nitrate, dissolved as N	Median	14	6.7	24	15	6.9	.42	1.6	.17
	n	7	7	7	3	4	7	7	6
	Minimum	13	1.1	15	14	6.8	.29	.69	.08
	Maximum	16	9.0	25	15	8.8	.99	1.8	3.6
Ammonia, dissolved as N	Median	.02	.02	.02	.02	.02	.02	.01	.02
	n	7	7	7	3	4	7	7	6
	Minimum	<.02	<.02	<.02	<.02	<.02	<.02	<.02	<.02
	Maximum	.11	.04	.05	.02	.02	.04	.04	.03
Ammonia + organic nitrogen, dissolved as N	Median	.42	.30	.36	.30	.30	.28	.30	.26
	n	7	7	7	3	4	7	7	6
	Minimum	.20	<.20	<.20	<.20	.26	<.20	<.20	<.20
	Maximum	1.3	.40	.60	.64	.50	.52	.52	.42
Phosphorus, dissolved as P	Median	.02	.03	.03	.03	.01	.02	.03	.02
	n	7	7	7	3	4	7	7	6
	Minimum	<.02	<.02	.03	.03	<.02	<.02	<.02	<.02
	Maximum	.06	.05	.07	.06	.02	.05	.06	.05

Table 7.3-15.--Benthic macroinvertebrate quantitative[1] results, USGS Conestoga Creek Project, Lancaster County

Taxa	Station 1		Station 3		Station 4	
	10/88	5/89	10/88	5/89	10/88	5/89
Ephemeroptera - mayflies						
Baetidae						
Baetis	11	39	1	–	1	76
Ephemerellidae						
Ephemerella	–	43	–	1	–	6
Heptageniidae						
Cinygmula	–	34	–	–	–	–
Epeorus	–	9	–	–	–	–
Leucrocuta	–	6	–	–	–	–
Stenonema	5	18	–	–	–	–
Leptophlebiidae						
Paraleptophlebia	2	16	–	–	–	–
Siphlonuridae						
Ameletus	–	3	–	–	–	–
Plecoptera - stoneflies						
Chloroperlidae	–	1	–	–	–	–
Haploperla	–	3	–	–	–	–
Suwallia-Sweltsa group	–	1	–	–	–	–
Nemouridae						
Amphinemura	–	1	–	–	–	–
Perlodidae						
Isoperla holochlora	–	4	–	–	–	–
Remenus	–	1	–	–	–	–
Trichoptera - caddisflies						
Glossosomatidae						
Glossosoma	3	–	–	–	–	–
Hydropsychidae						
Cheumatopsyche	2	13	3	2	7	9
Diplectrona	33	20	–	–	–	–
Hydropsyche (Ceratopsyche)	16	15	–	–	42	19
Hydropsyche (Hydropsyche)	5	15	9	1	83	22
Polycentropodidae						
Polycentropus	2	3	–	–	–	–
Rhyacophilidae						
Rhacophila carolina	4	2	–	–	–	–
Rhacophila invaria group	1	5	–	–	–	–
Uenoidae						
Neophylax	–	12	–	–	–	1
Diptera - true flies						
Ceratopogonidae						
Bezzia group (n.r.)	–	–	–	3	–	–
Chelifera	–	1	–	–	–	–
Hemerodromia	–	10	–	16	–	9
Simuliidae						
Simulium	1	2	212	262	131	1,545
Tipulidae	1	–	–	–	–	–
Antocha	–	7	–	–	–	35
Tipula	–	1	–	–	–	–
Chironomidae	3	137	40	919	73	331

Table 7.3-15.--Benthic macroinvertebrate quantitative[1] results, USGS Conestoga Creek Project, Lancaster County--Continued

Taxa	Station 1 10/88	Station 1 5/89	Station 3 10/88	Station 3 5/89	Station 4 10/88	Station 4 5/89
Other Insect Taxa						
Odonata - dragon-damselflies						
Coenagrionidae						
Enallagma or *Ischnura* n.r.	–	–	1	–	–	–
Coleoptera - aquatic beetles						
Dystiscidae	–	–	2	2	–	–
Elmidae						
Dubiraphia	–	1	1	–	–	–
Stenelmis	–	61	4	18	3	1
Eubriidae						
Ectopria	–	–	1	–	–	–
Hydrophilidae	–	–	–	–	1	1
Non-Insect Taxa						
Turbellaria - flatworms	–	–	53	–	5	–
Cura	–	–	46	–	13	1
Dugesia	–	2	–	141	–	–
Oligochaeta - lumbricid type	2	1	5	–	4	2
Oligochaeta - tubificid type	–	–	55	52	40	185
Hirudinea - leeches	–	–	1	3	15	1
Isopoda - aquatic sowbugs						
Asellidae						
Asellus	–	–	190	20	22	5
Decapoda - crayfish						
Cambaridae	–	3	–	–	–	–
Orconectes	–	–	–	–	1	–
Gastropoda - univalves, snails						
Physidae	–	–	1	–	–	–
Physa	–	–	–	11	–	–
Physella n.r.	–	–	–	–	1	8
Planorbidae	–	–	6	83	2	–
Hydracarina	–	–	–	2	–	–
Ostracoda	–	–	–	111	–	–
Total Number Taxa[2]	15	32	17	17	16	18
Individuals	91	490	631	1,647	444	2,257

[1] Combined totals of 3 surber sq. ft. samples.

[2] Total number taxa does not include "family" taxon level where genera in that family have already been identified.

At Station 3, about 3.1 km downstream of Station 1 seventeen total taxa were collected in both 1988 and 1989. The community was again dominated by hydropsychid caddisflies and midges included the occurrence of flatworms.

The community at Station 4 was dominated by hydropsychid caddisflies, midges, and black flies. Sixteen total taxa were collected in 1988 versus 18 in 1989.

The greatest difference in physical and chemical characteristics between the two samplings was the higher water temperature during the May 1988 sampling, and higher concentrations of suspended solid, nitrogen, and phosphorus at Stations 3 and 4 than at Station 1 where minimal agricultural activity took place.

7.4 FIELD-SITE 1

The 22.1-acre site, which is underlain by carbonate rock, is located in the Conestoga River headwaters, between Churchtown and Goodville, Lancaster County, Pennsylvania (fig. 6-1). The site, part of two dairy farms, was conventionally tilled cropland and was planted primarily in corn and alfalfa during the study period. The silt loam soils are up to 60 in. deep and are moderately to well drained. The site has an average slope of about 6 percent (see Section 6.9 for full description).

For Field-Site 1 data analysis in this report, the pre-BMP period, from January 1983 through September 1984 is referred to as Period 1. Data from the post-BMP portion of the study is grouped into three time periods: October 1984 through September 1986 (1985 and 1986 water years) is referred to as Period 2, October 1986 through September 1988 (the 1987 and 1988 water years) is referred to as Period 3, and October 1988 through September 1989 (the 1989 water year) is referred to as Period 4. As documented in the following sections, Period 3 in the post-BMP period is the most comparable to Period 1, the pre-BMP period in terms of annual precipitation and nutrient applications to the field. (The 1988 water year is comparable to the 1983 water year and the 1987 water year is comparable to the 1984 water year.) In addition, by Period 3 the terraces were well established (settled) and cropping patterns were stable. Therefore, data from Period 3 and Period 1 are compared more frequently throughout this report for interpretive discussion and determination of changes due to BMPs. The 1989 water year data was not used as frequently for comparative analysis as the other periods because: (1) the cropping pattern for the 1989 water year differed radically from all previous years studied, for example the amounts of cropland in corn and alfalfa changed from 65-80 percent corn and 35-20 percent alfalfa in Periods 1, 2, and 3-10 percent corn and 90 percent alfalfa in Period 4; (2) regularly scheduled data collection ended in July 1989, so the water year's data is incomplete; and (3) the duration of the 1989 water year data record is less than half that of the other periods. Because the inclusion of data from Period 4 would be misleading in some of the comparative analyses, it is excluded from some of the analyses in this report. Data from the entire post-BMP period is also at times compared to the pre-BMP period.

7.4.1 Field-Site 1 Precipitation

During the post-BMP period, annual precipitation at Field-Site 1 ranged from 35.6 inches during the 1985 water year to 46.2 inches during the 1987 water year (table 7.4-1).

Normal precipitation at Field-Site 1 is about 41.5 inches per year, based on the 30-year average (1951-80) at Morgantown, Pennsylvania, the location of a nearby National Oceanic and Atmospheric Administration (NOAA) station (National Oceanic and Atmospheric Administration, 1985). In comparison, the pre-BMP period, Period 1, was about 25 percent wetter than normal, or 35 percent wetter than Period 2, 19 percent wetter than Period 3, and 16 percent wetter than Period 4.

The distribution of monthly precipitation varied dramatically from year to year and period to period (fig. 7.4-1). Figure 7.4-1 compares total monthly precipitation at Field-Site 1 to the 30-year monthly normal. With the exception of the month of December, the largest variations in total monthly precipitation occurred in the warmer months (April through September).

Table 7.3-16.--Water-quality data collected during benthic macroinvertebrate sampling in the Small Watershed

[all values in milligrams per liter, except as noted; °C, degrees Celsius; MPN/100 ml, most probable number per 100 milliliters]

	Station 1		Station 3		Station 4	
	10-25-88	5-15-89	10-25-88	5-15-89	10-25-88	5-15-89
Field analyses						
Temperature (°C)	8.9	11.0	9.0	15.0	12.9	16.0
Dissolved oxygen	10.2	10.6	12.8	11.6	10.4	9.5
Specific conductance (micromhos/cm)	50	40	278	200	245	225
pH	6.7	7.3	7.7	7.7	7.7	7.6
Laboratory analyses						
BOD (5-day)	1.6	<.4	1.6	<.4	3.2	.4
pH	6.7	6.2	8.1	7.0	7.8	6.9
Alkalinity	16	10	142	78	100	76
Total suspended solids	58	20	390	164	270	238
Volatile suspended solids	<2	16	6	24	8	28
Total NH_3-N	<.02	.02	.1	.06	.14	.08
Total NO_2-N	<.01	<.01	.15	.03	.06	.03
Total NO_3-N	2.9	2.7	8.4	7.1	4.6	6.9
Total NH_3 + organic-N	<.20	<.20	.52	.32	.82	.99
Total phosphorus	.05	.04	.32	.15	.21	.17
Chloride	5	4	13	9	14	11
Total coliform (MPN/100 ml)		100		2,200		4,000
Fecal coliform (MPN/100 ml)		20		800		2,100

Table 7.4-1.--Annual precipitation at Field-Site 1 and the 30-year mean at Morgantown, PA

		Precipitation, in inches	
Period	Dates	Field-Site 1	Morgantown[1] (1951-80)
1	Jan. 1-Sept. 30, 1983	31.4	31.9
	Oct. 1, 1983-Sept. 30, 1984	59.8	41.5
2	Oct. 1, 1984-Sept. 30, 1985	41.7	41.5
	Oct. 1, 1985-Sept. 30, 1986	35.6	41.5
3	Oct. 1, 1986-Sept. 30, 1987	46.2	41.5
	Oct. 1, 1987-Sept. 30, 1988	41.3	41.5
4	Oct. 1, 1988-Sept. 30, 1989	45.0	41.5

[1] Data from the National Oceanic and Atmospheric Administration (1985).

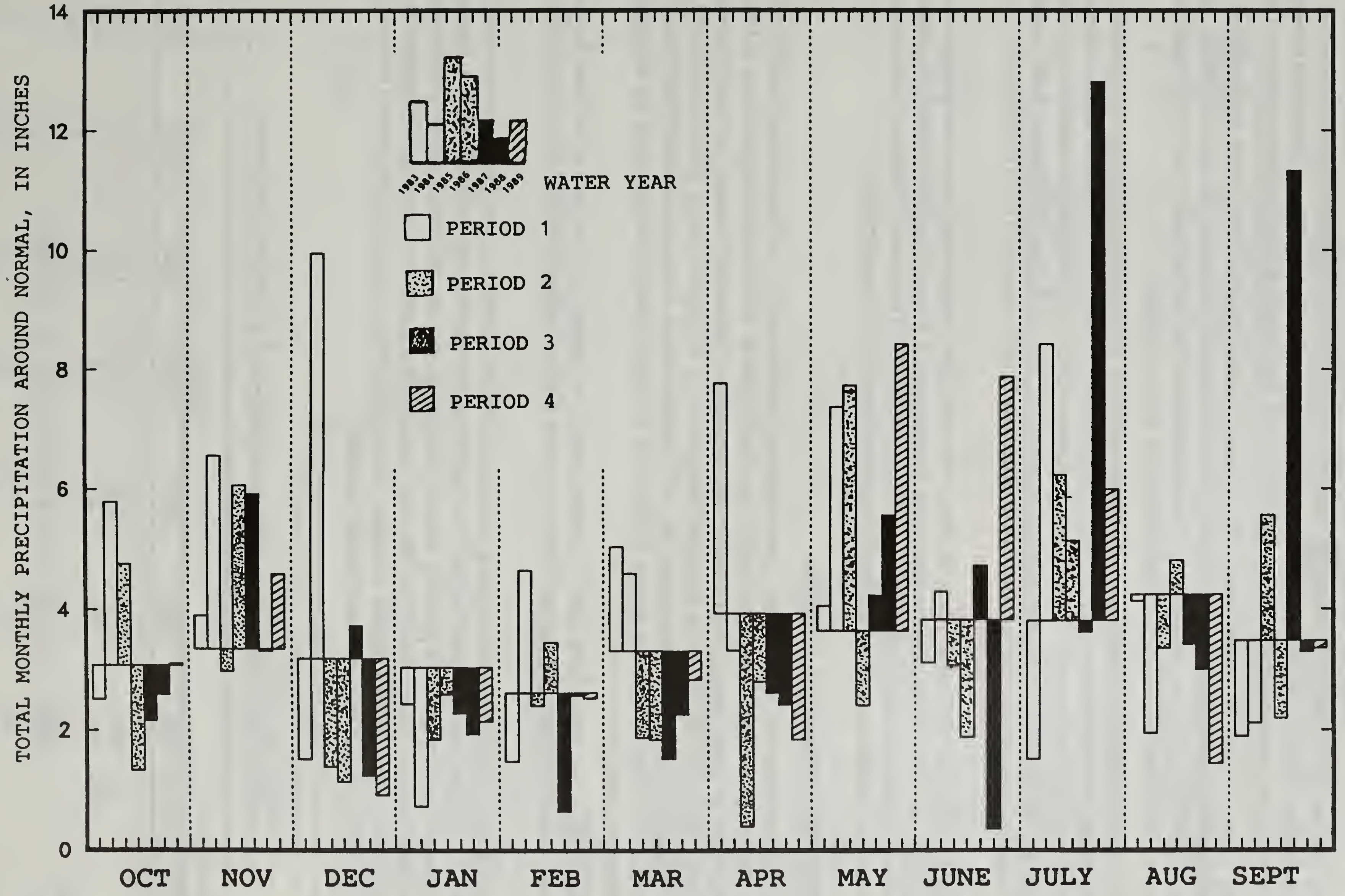


Figure 7.4-1.-- Total monthly precipitation around normal (30-year average from a National Oceanographic and Atmospheric Administration Weather Station at Morgantown, PA [NOAA, 1985]).

The number and distribution of precipitation events, as well as their intensities and durations, influence the amounts of runoff and recharge. For the purpose of this report, a storm is defined as a minimum of 0.10 in. of precipitation bounded by an interval of 1 hour or more, of less than 0.014 in. of precipitation.

During the pre-BMP Period 1, 169 storms occurred (fig. 7.4-2). The median storm precipitation was 0.29 in., the median storm duration was 2.8 hours, and the median maximum 15-and 30-minute intensities were 0.08 and 0.13 in., respectively (Lietman and others, U.S. Geological Survey, written commun., 1991).

During Period 2 (1985-86 water years), 136 storms occurred. Median total storm precipitation was 0.30 in., median storm duration was 3.0 hours, and the median maximum 15- and 30-minute storm intensities were 0.10 and 0.13 in., respectively. Nineteen storms in the period had a total precipitation of 1.0 in. or greater, and two storms had a total precipitation of 2.0 in. or greater.

During Period 3 (1987-88 water years), 148 storms occurred. The median total storm precipitation was 0.33 in., the median storm duration was 3.4 hours, and the median maximum 15- and 30-minute intensities were 0.07 and 0.10 in., respectively. There were 24 storms with a total precipitation amount of 1.0 in. or greater, and six storms with a total precipitation amount of 2.0 in. or greater. The largest storm recorded during the entire 7-year study period occurred on September 8, 1987, when 6.70 in. of rain fell in an 11-hour period.

During Period 4 (the 1989 water year), 80 storms occurred. The median total storm precipitation during the 1989 water year was 0.28 in., the median storm duration was 2.6 hours, and the median maximum 15- and 30-minute storm intensities were 0.07 and 0.11 in., respectively. There were 10 storms producing more than 1.0 in. of precipitation and 2 storms producing more than 2.0 in. of precipitation.

7.4.2 Field-Site 1 Agricultural Activities

The BMP implemented at Field-Site 1 was terracing. Additionally, a nutrient management plan was drawn up for the site. A manure storage facility was constructed to allow manure applications to be made close to the time of plant usage, and to reduce the necessity of spreading manure on frozen ground. A description of these two BMPs can be found in Section 6.9.3 of this report, along with maps showing the change in topography as a result of terracing (fig. 6-5). Field locations, acreages, and identification numbers after construction of the terraces are shown in figure 7.4-3. Terrace construction involved the acreage from fields 2 through 7 and 11.

In this section, the term "crop year" is often used. It is defined as the interval of time beginning immediately after the harvest of one year's corn crop at the site and ending with the harvest of the next corn crop.

Year-to-year crop acreages and cropping patterns for the 1983-1989 crop years are shown in table 7.4-2 and figure 7.4-4. There was a substantial shift in cropping at the site through the study period. During the pre-BMP period and also the 1985 growing season, corn was grown on about 75-80 percent of the site and alfalfa on 15-20 percent. During the 1986-1988 crop years, 58-67 percent of the acreage was planted in corn and 33-38 percent was planted in alfalfa. However, during the 1989 crop year, only 34 percent of the acreage was planted in corn and 59 percent was planted in alfalfa.

Table 7.4-2--Crops and acreage at Field-Site 1, 1983-89 crop years

	Acres						
Crop	1983	1984	1985	1986	1987	1988	1989
Corn	14.4	14.4	17.9	13.3	14.2	15.4	7.3
Alfalfa	5.4	5.4	4.2	8.8	7.7	7.7	14.2
Soybeans	.0	.0	.0	.8	1.1	.0	1.6
Tobacco	1.9	.0	1.0	.2	.0	.0	.0
Rye	.0	1.9	.0	.0	.0	.0	.0
Pumpkins	.4	.4	.0	.0	.0	.0	.0

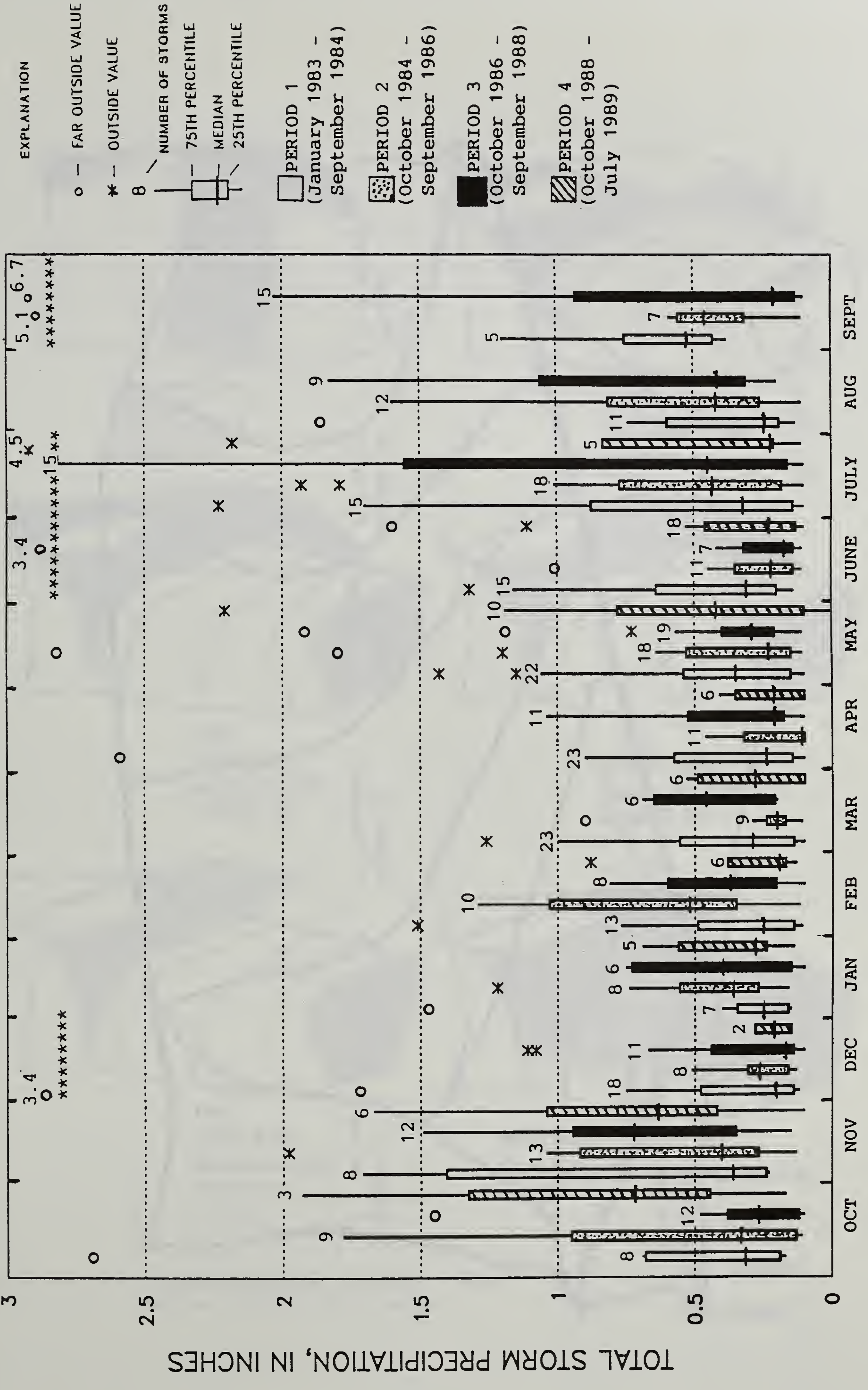


Figure 7.4-2.-- Distribution of total storm precipitation at Field-Site 1.

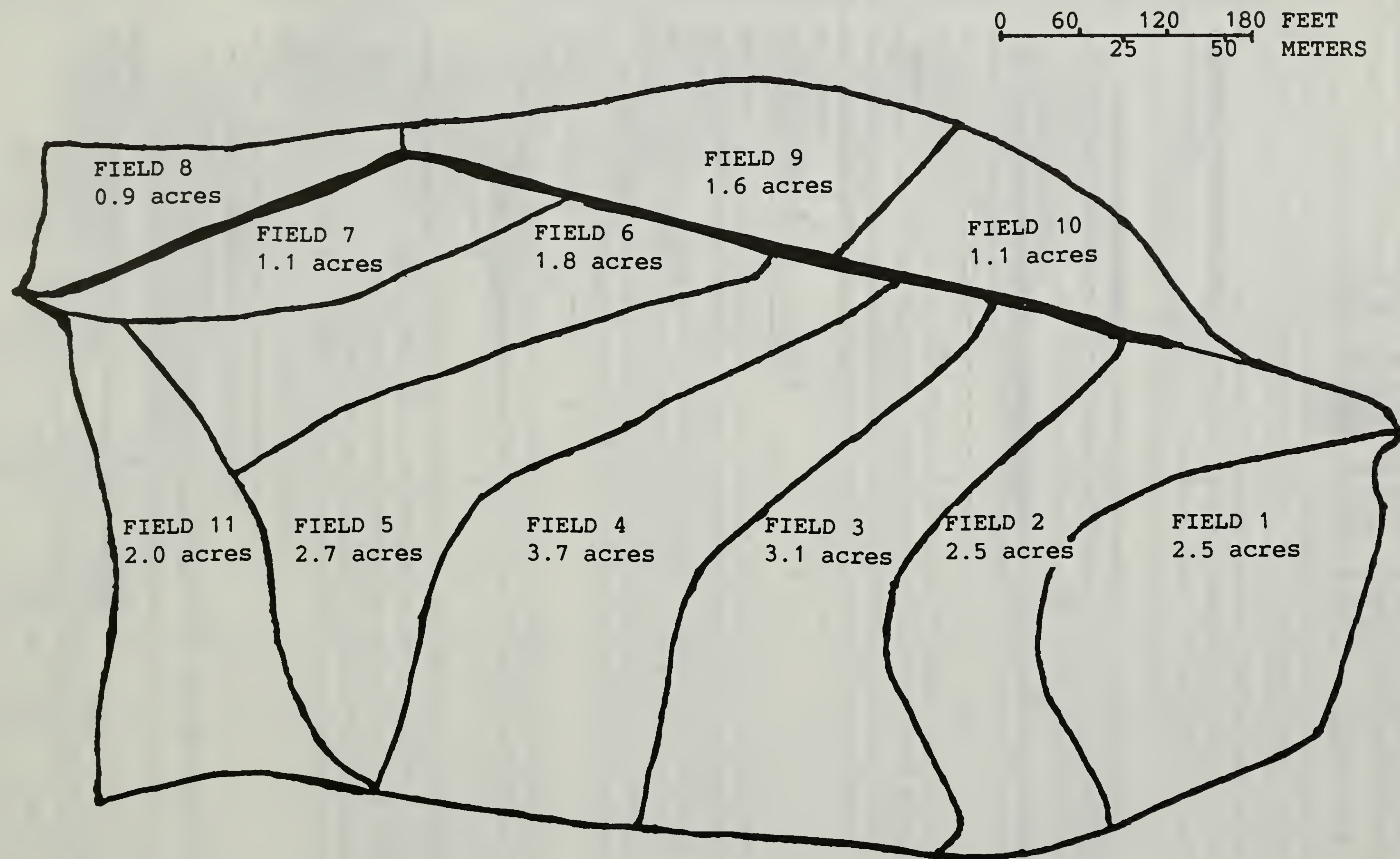


Figure 7.4-3.-- Field identification numbers, locations, and acreages at Field-Site 1 after terrace construction in October 1984.

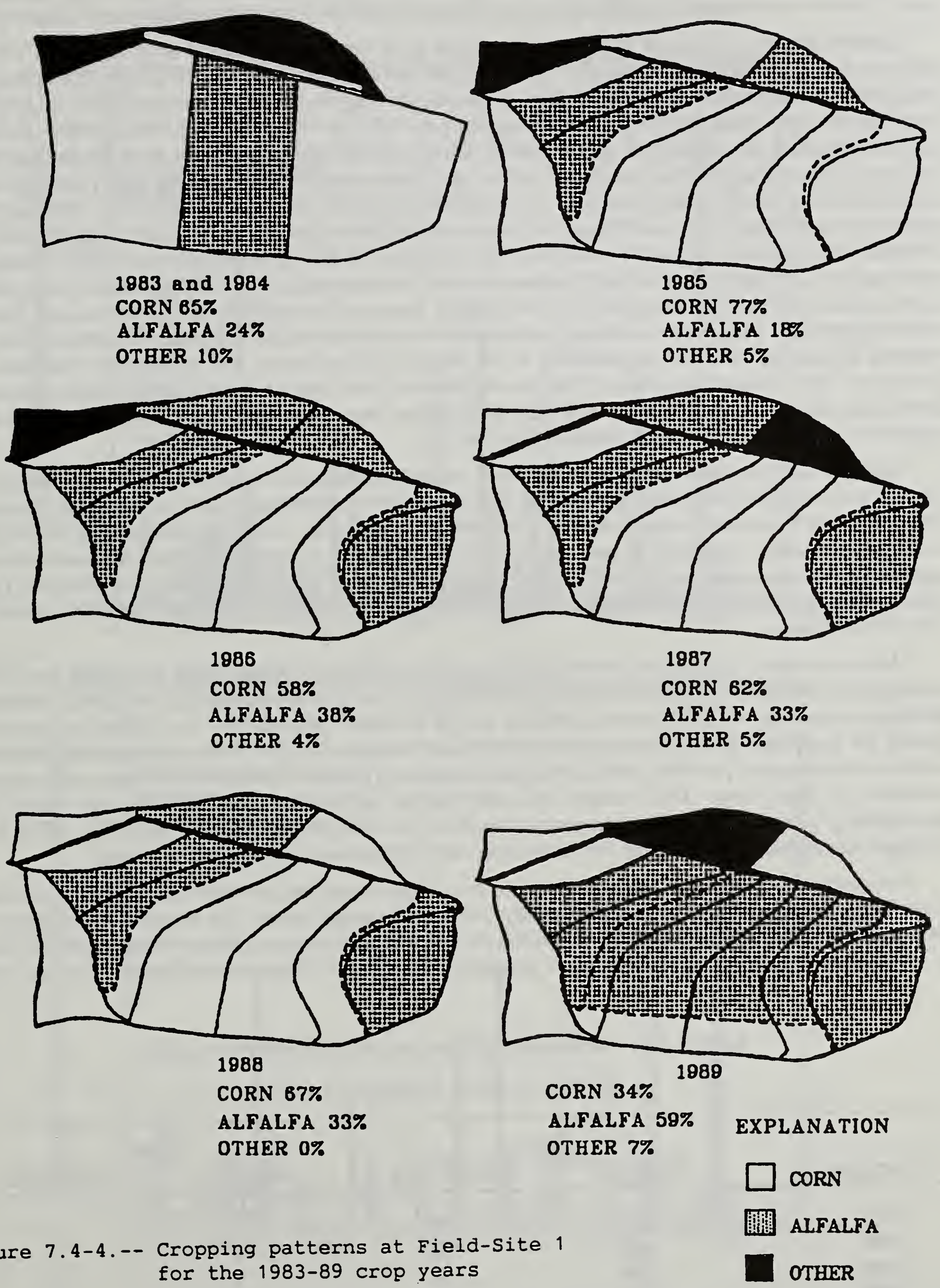


Figure 7.4-4.-- Cropping patterns at Field-Site 1 for the 1983-89 crop years

Annual totals of nitrogen and phosphorus applications are tabulated by crop year rather than by water year in order to most accurately determine the amount of applied nutrients available to a season's crop.

Distribution and timing of manure applications is an important factor to consider when utilizing a nutrient-management practice. Figure 7.4-5 shows the monthly total amounts of nitrogen and phosphorus as manure or commercial fertilizer, applied to the site during the pre-BMP and post-BMP study periods. Applications were made less frequently during the post-BMP period than the pre-BMP period. During the post-BMP period, the majority of the pit manure (dairy manure and wash water from the manure storage pit) was generally applied to the fields in the springtime soon before plowing and planting; another application was usually made following crop harvest in the fall. During the 1985, 1986, 1988 crop years, most of the nutrients (74, 81, and 92 percent, respectively) were applied after January 1, usually just before the fields were plowed. During the 1987 and 1989 crop year, 54 and 6 percent of the nutrients were applied after January 1, respectively. The heifer manure was not incorporated into the storage facility and continued to be spread periodically. During the pre-BMP period, manure was applied almost every month that crops were not growing on the field, including winter months when the soil was frozen. The construction of the manure storage pit allowed applications to be made less frequently and when soil conditions were favorable. Figure 7.4-6 shows rates of nitrogen application in lb/acre to the individual fields. Because crop boundaries do not always coincide with field boundaries, rates of nitrogen applied reflect the spacial and temporal distribution, not the application rates per crop.

Nitrogen and phosphorus applications were spatially distributed about the same over the site since most of the nutrients were from manure. The largest nutrient applications per crop year were made for the 1987 crop, 423 lb/acre of nitrogen and 112 lb/acre of phosphorus. However, distribution across the site varied dramatically from year to year and field to field. Fields 8-10 generally had substantially smaller applications of nutrients than the other fields. Fields 2, 3, 4, and 7 generally had larger application than the other fields. Applications of more than 1,000 lb/acre were made to Fields 2 and 3 for the 1987 crop and Field 7 for the 1989 crop.

Manure nutrient applications were concentrated on the corn acreage while the alfalfa and soybean acreage received relatively low nutrient applications (table 7.4-3), predominantly in the form of commercial fertilizer. An average of 385 lb/acre of nitrogen and 92 lb/acre of phosphorus was applied per acre of corn during the post-BMP period, compared to 410 lb/acre nitrogen and 110 lb/acre phosphorus applied per acre of corn during the pre-BMP period resulting in about a 6 percent reduction of nitrogen and a 16 percent reduction in phosphorus. The nitrogen and phosphorus applications made to corn and alfalfa varied dramatically, however, from one crop year to another. For example, for the 1987 corn crop, 685 lb/acre of nitrogen was applied while for the 1985 corn crop only 230 lb/acre of nitrogen was applied.

The nutrient management plans were based on nitrogen only, and always recommended an excess of phosphorus when manure was used to satisfy the crops nitrogen needs. The nutrient management plan developed in 1985 for fields 1-7 and 11 recommended an annual nitrogen application rate of 350-375 lb/acre of nitrogen within 5-7 days of plowing of cornfields (less than a 15 percent reduction from that applied

Table 7.4-3.--Nutrient applications to Field-Site 1 by crop

[all values are in pounds per acre]

Crop year	Corn		Alfalfa	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus
1983	150	33	0	0
1984	640	170	31	8
1985	230	61	9	15
1986	290	72	7	12
1987	690	130	24	0
1988	300	80	0	0
1989	540	160	290	84

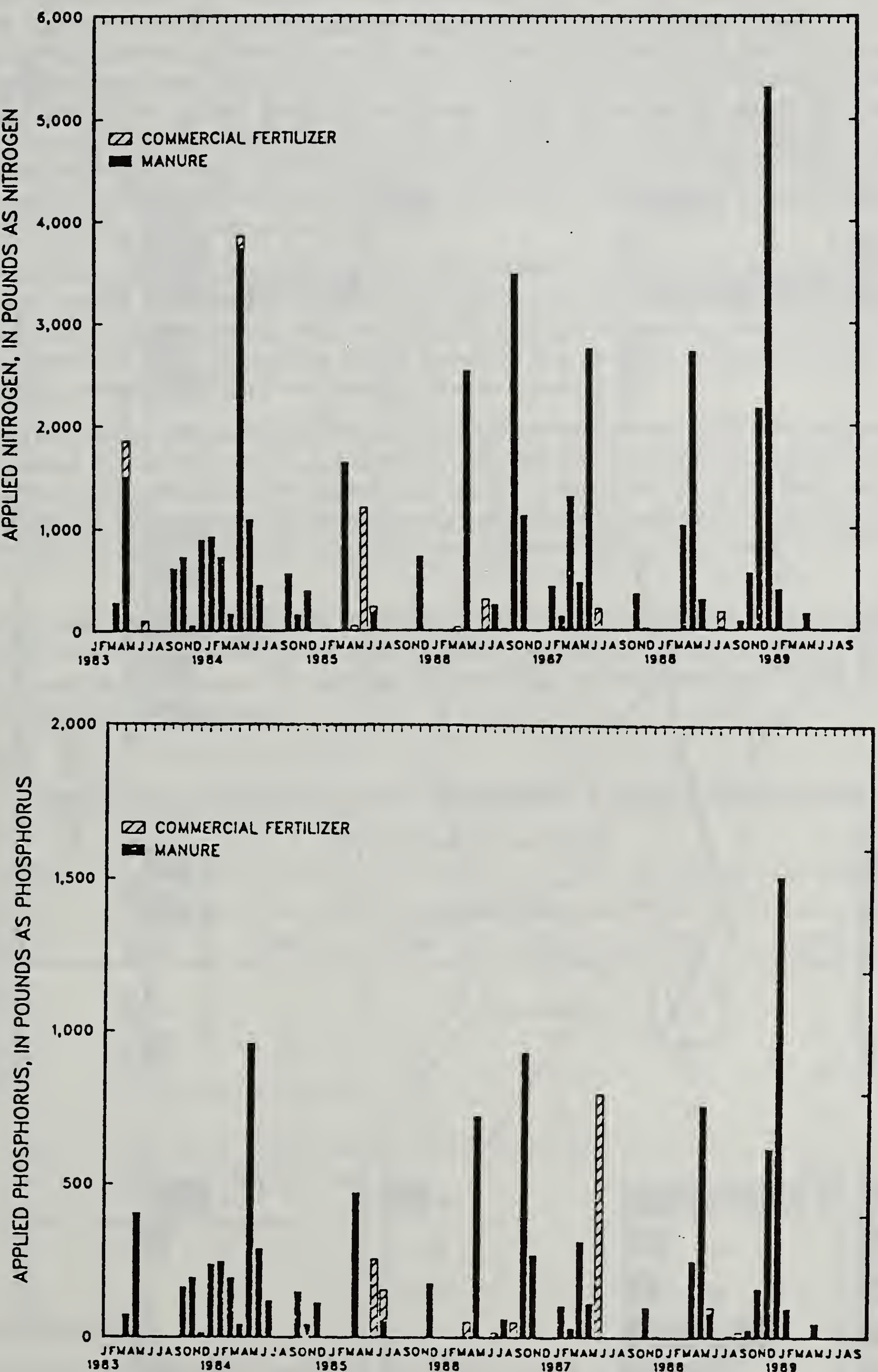


Figure 7.4-5.-- Nitrogen and phosphorus applications to Field-Site 1.

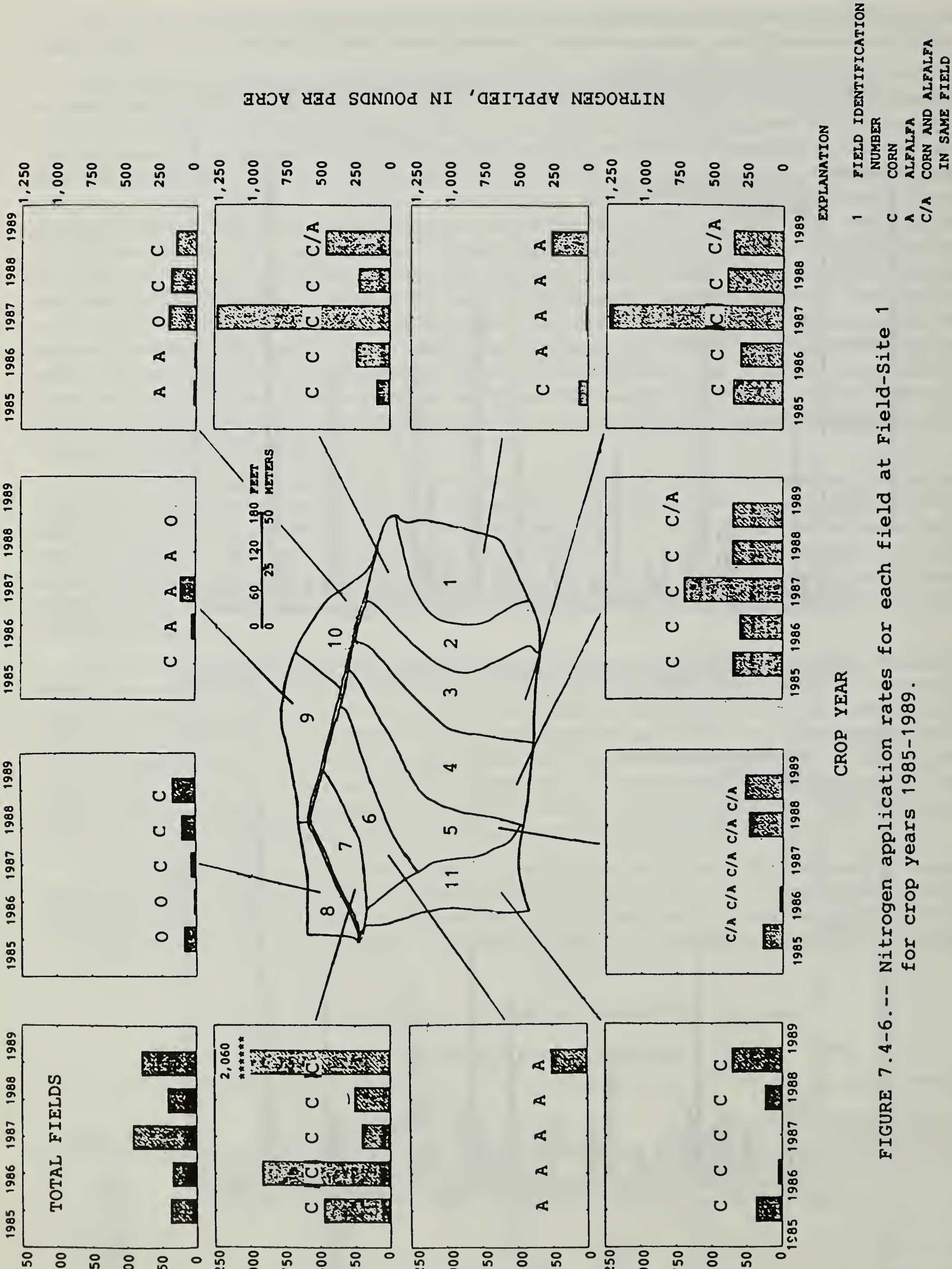


FIGURE 7.4-6.-- Nitrogen application rates for each field at Field-Site 1 for crop years 1985-1989.

during the pre-BMP period) and an average application rate of 100 lb/acre of nitrogen for newly seeded alfalfa fields (with no application recommended on established alfalfa). With the manure incorporated into the soil by plowing 5-7 days after application, and considering the nitrogen available from previous years applications, approximately 65 percent of the nitrogen applied should be available for the crop (includes 30 percent from the present application and 35 percent from applications for previous years) (estimated using information from Penn State Agronomy Guide, 1989). The manure phosphorus is considered to be available the year it is applied (Robert Anderson, written communication, Penn State University Cooperative Extension Service, 1985). The nutrient management plan revised for the 1989 crop year made about the same recommendations for the corn crops and about 1.5 times the 1985 recommendation for new alfalfa. The largest manure applications during the post-BMP period generally were made in the spring months a few days to weeks prior to plowing.

The agricultural-activities data collected from the farmers were not accurate enough for each year to determine the specific number of days between applications and plowing (incorporation). The data, however, did indicate that at least in 1986 and 1988, the large pit manure applications made in the spring were made within 1-2 days of plowing which increased the available nitrogen from 65 to 85 percent (estimated using information from Penn State Agronomy Guide, 1989).

Although the average rate calculated for the post-BMP period does fall within the range recommended, it should be noted that distribution of applications were not consistent throughout the pre-BMP or post-BMP period. Even with adjustment to applications for rapid incorporation of a substantial portion of the manure for 1986 and 1988, nutrient management recommendations were followed within 25 percent in the 1985, 1986, 1988 crop years. However, the plans were exceeded by about 2.5 times in 1987 and 1989 crop years.

Herbicides were applied primarily to the cornfields throughout the 7-year study period. The primary herbicides that were used and were analyzed for in water and soil samples were atrazine, metolachlor, and cyanazine. In addition, simazine was applied to the alfalfa in December 1987. Table 7.4-4 shows the quantities and years of application.

Table 7.4-4.--Herbicides applied to Field-Site 1, as reported by farmers

[Herbicides, in pounds]

	Water year						
Herbicide	1983	1984	1985	1986	1987	1988	1989
Atrazine[1]	14	26	6	14	11	7	3
Metolachlor[1]	22	34	8	17	0	2	12
Cyanazine[1]	0	0	0	0	23	13	6
Simazine[2]	0	0	0	0	8	0	0

[1]Applied to cornfields in May or June.

[2]Applied to alfalfa in December.

7.4.3 Field-Site 1 Soils

General soil characteristics at the site are discussed in detail in Section 6.9.5.

The particle-size, nutrient, and herbicide data presented in this paper are used to help characterize the soil at the site during the post-BMP period, and contrast the post-BMP data to pre-BMP data in relation to factors influenced by BMP implementation. Statistical comparisons are not made because of the limited number of samples and the large variability in the data.

Median, minimum, and maximum soil-nutrient concentrations in cornfields 3 and 4, and alfalfa field 5 are shown in table 7.4-5. Median soil-nitrate concentrations for the corn or alfalfa fields ranged from 16 to 39 lb/acre for the 0-8 in. depth (the plow layer), from 32 to 86 lb/acre for the 0-24 in. depth, and from 45 to 104 lb/acre for the 0-48 in. depth (the corn root zone). Median soil-phosphorus concentrations for the corn or alfalfa fields ranged from 0.5 to 2.5 lb/acre for 0-8 in. depth, 0.7 to 3.0 lb/acre for the 0-24 in. depth and from 1.0 to 4.0 lb/acre to the 0-48 in. depth. (Reported phosphorus values may be converted to phosphate (P_2O_5) by multiplying the phosphorus values by 2.3.)

Two post-BMP samples of the top 2-in. of soil (composited from 13 locations spread over the site), analyzed for particle-size after removing any particles greater than 2.0 mm in diameter, contained 9-12 percent sand, 59-61 percent silt, and 29-30 percent clay by weight. Only 1-4 percent of the samples by weight was greater than 2.0 mm. One of the samples was collected in April 1985, the spring following terrace construction, and the other was collected in June 1985, following reconstruction of the terraces after runoff topped and partially-washed out the terraces following a large thunderstorm. In contrast, 2-in. samples collected during the pre-BMP period (which only varied by 2 percent), contained 17 percent sand, 57 percent silt, and 26 percent clay. The portion greater than 2.0 mm was 4 to 17 percent of the sample by weight.

Movement of the soils during terrace construction probably caused some differences in the particle-size distribution. A 2-in. composite soil sample collected from the whole site in April 1986 contained no material greater than 2.0 mm in diameter, 34 percent sand, 47 percent silt, and 19 percent clay. This may be due to finer soil particles washing from the back sides of the terraces into the terrace bottoms. A particle-size

Table 7.4-5.--Summary statistics of soil nutrient data for samples collected from November 1984 through June 1989 (No samples were collected during the spring of 1985 and 1989 and during the summer of 1985.)

[Med, median; Min, minimum; Max, maximum; lb, pounds; --, no data]

		Corn (Fields 3 and 4)				Alfalfa (Field 5)			
Sampling period	Depth, in inches	Number of samples	Med	Min	Max	Number of samples	Med	Min	Max
				(lb N/acre)					
Fall	0-8	10	33	15	115	3	19	12	23
	0-24	10	65	26	167	3	32	25	40
	0-48	10	104	40	198	3	72	43	52
Spring	0-8	8	16	13	29	3	20	18	33
	0-24	8	50	37	96	3	39	33	49
	0-48	8	98	52	261	3	45	44	64
Summer	0-8	8	39	11	112	4	28	13	39
	0-24	8	86	18	286	4	59	26	73
	0-48	0	--	--	--	0	--	--	--
				(lb P/acre)					
Fall	0-8	10	1.2	.4	3.9	3	2.5	1.8	3.5
	0-24	10	1.4	.6	4.2	3	3.0	2.0	4.1
	0-48	10	2.0	1.0	5.6	3	4.0	2.2	4.5
Spring	0-8	8	.5	.1	1.7	3	2.0	.5	3.2
	0-24	8	.7	.4	2.9	3	2.2	.8	3.4
	0-48	8	1.0	.6	4.6	3	2.6	1.0	3.6
Summer	0-8	8	.9	.1	11	4	1.0	.5	2.0
	0-24	8	1.2	.3	13	4	1.5	.6	2.3
	0-48	0	--	--	--	0	--	--	--

sample of terrace bottom soil, collected on the same day in April 1986, contained no material greater than 2.0 mm in diameter, 19 percent sand, 54 percent silt, and 27 percent clay.

A profile of the average nitrate and phosphorus concentrations by depth is shown in figures 7.4-7 through 7.4-10.

Median nitrate concentrations for the 0-8 and 0-24-in. depths are greater in the summer than in the fall or spring for both corn and alfalfa fields and were greater in samples from the cornfields than from the alfalfa field, regardless of depth or sampling period, except for the 0-8-in. depth during the spring sampling period. Median phosphorus concentrations for all depths were greatest in the fall samples and were always less in samples from the cornfields than from the alfalfa field, regardless of depth or sampling period.

Except for two samples collected in the fall of 1985 at cornfield 3 and in the summer of 1986 at cornfield 4, the nitrate concentrations were larger in the 0-8 in. samples than the 8-24 in. samples. Soil data from the cornfield indicates a general downward movement of soil nitrate during the winter, which is reflected in lower nitrate concentration in the 0-8 in. soil layer and more variable soil nitrate concentrations in the deeper soil layers sampled in the spring. However, nitrate concentrations decreased with depth in soil samples collected in the spring from the alfalfa field.

The soluble phosphorus concentrations were larger in the 0-8 in. soil samples than in the deeper soil samples, except for one, regardless of site or season. The phosphorus concentrations in samples below 8 in. were generally less than 0.5 (lb/in)/acre.

The higher soil nitrate (4-14 lb/in/acre) and phosphorus [0.10 - 1.4 (lb/in)/acre] concentrations in the shallow soil samples from cornfields were all found after the large nutrient applications for the 1987 crop.

In contrast, the nutrient concentrations in the alfalfa field did not appear to be related to applications.

The average soil concentration of nitrate and phosphorus in the top 8 in. of soil in the spring of 1984 during the pre-BMP period was 20 and 0.5 lb/acre, respectively, and represented the entire site. Limited data indicated that this did not vary substantially during the post-BMP period. Median nitrate concentrations of 16 lb/acre in corn and 20 lb/acre in alfalfa and median phosphorus concentrations of 0.5 lb/acre in corn and 2.0 lb/acre in alfalfa were measured in the post-BMP period (table 7.4-5). This would be expected because there was not a significant change in nutrient application amounts from the pre-BMP to post-BMP period. During terracing, the soil was mixed, and redistributed. However, this did not appear to affect soil nutrient concentrations.

In the top 2 feet of soil the median soil concentration of nitrate in the fall of 1983 during the pre-BMP period was about 60 lb/acre and represented one sample from each of the two cornfields and one from the alfalfa field (Lietman and others, U.S. Geological Survey, written commun., 1991). This is about the same as the post-BMP period, when a median of 65 lb/acre in corn and 32 lb/acre in alfalfa (table 7.4-5) were measured.

Herbicide concentrations in the top 2-in. of soil did not change substantially during the 5 years they were sampled in the pre-BMP and post-BMP periods (1983-1987) (fig. 7.4-11). Concentrations of atrazine, which was applied to the cornfields in the spring of each year, ranged from less than 0.20 to 0.72 µg/kg. Metolachlor in soils was only analyzed for after September 1985. Metolachlor, applied each spring to the cornfields, except in 1987, was detected in 3 of 6 samples with concentrations of 30 µg/kg in October 1985, 900 µg/kg in May 1976, and 20 µg/kg in September 1986. Cyanazine, applied to the cornfields only in the spring of 1987, was found in one sample at a concentration of 430 µg/kg in June 1989. In addition to the herbicides reported to be applied to the site during the study period, alachlor, at a concentration of 50 µg/kg, and simazine, at a concentration of 120 µg/kg were found in the May 1986 soil samples.

7.4.4 Field-Site 1 Surface-Runoff Quantity and Quality

Surface runoff during the pre-BMP period was unimpeded by structural devices and it created small feeder gullies and larger receiving gullies in the lower cornfield. In contrast, most surface runoff during the post-BMP period, after installation of the terraces, discharged through the pipe-outlet system. Twice, under extreme storm conditions, runoff breached the terrace structures. Measurable runoff from Field-Site 1

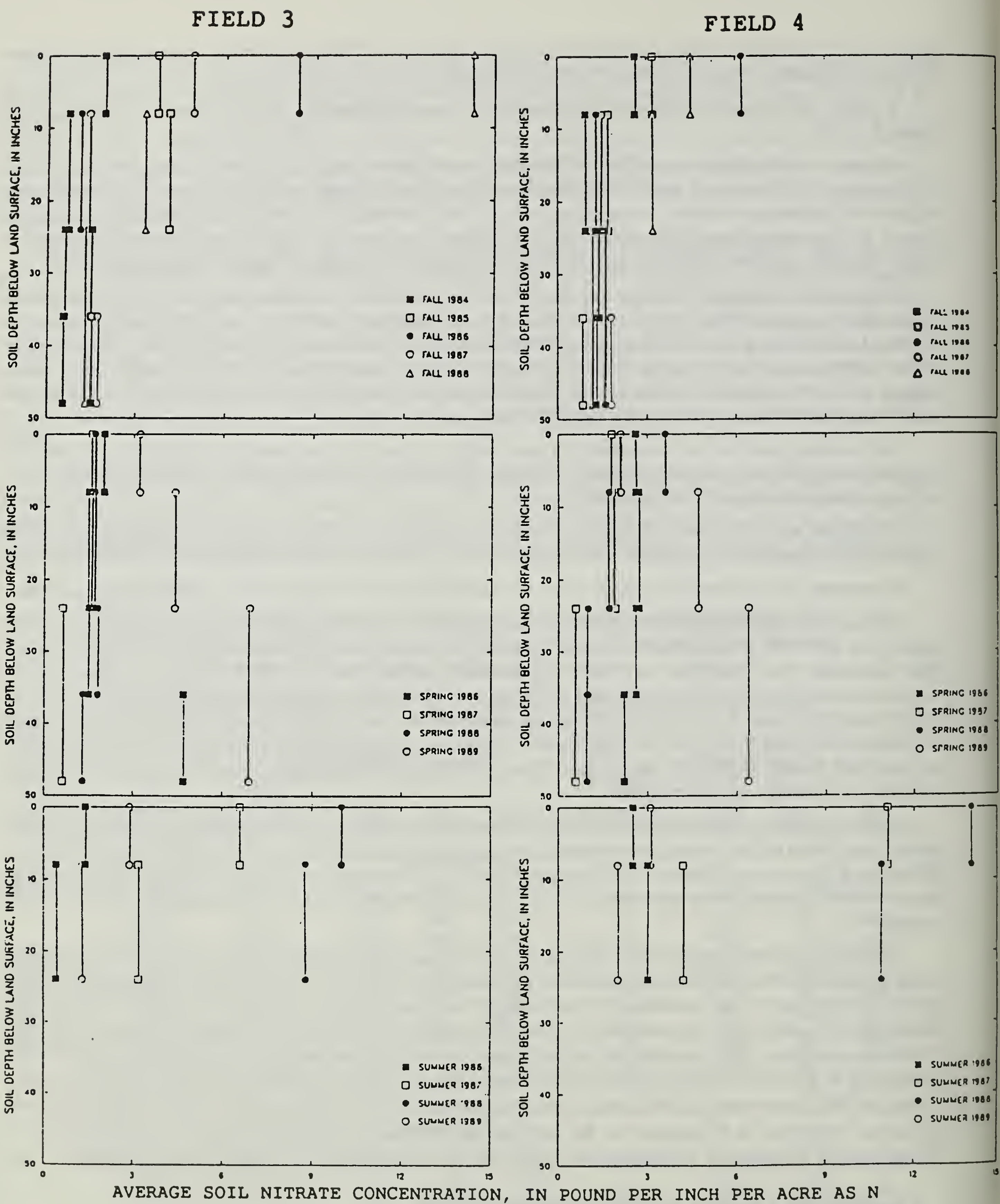


Figure 7.4-7.-- Nitrate concentrations in soil samples collected from Fields 3 and 4 (planted in corn) at Field-Site 1, 1984-1989.

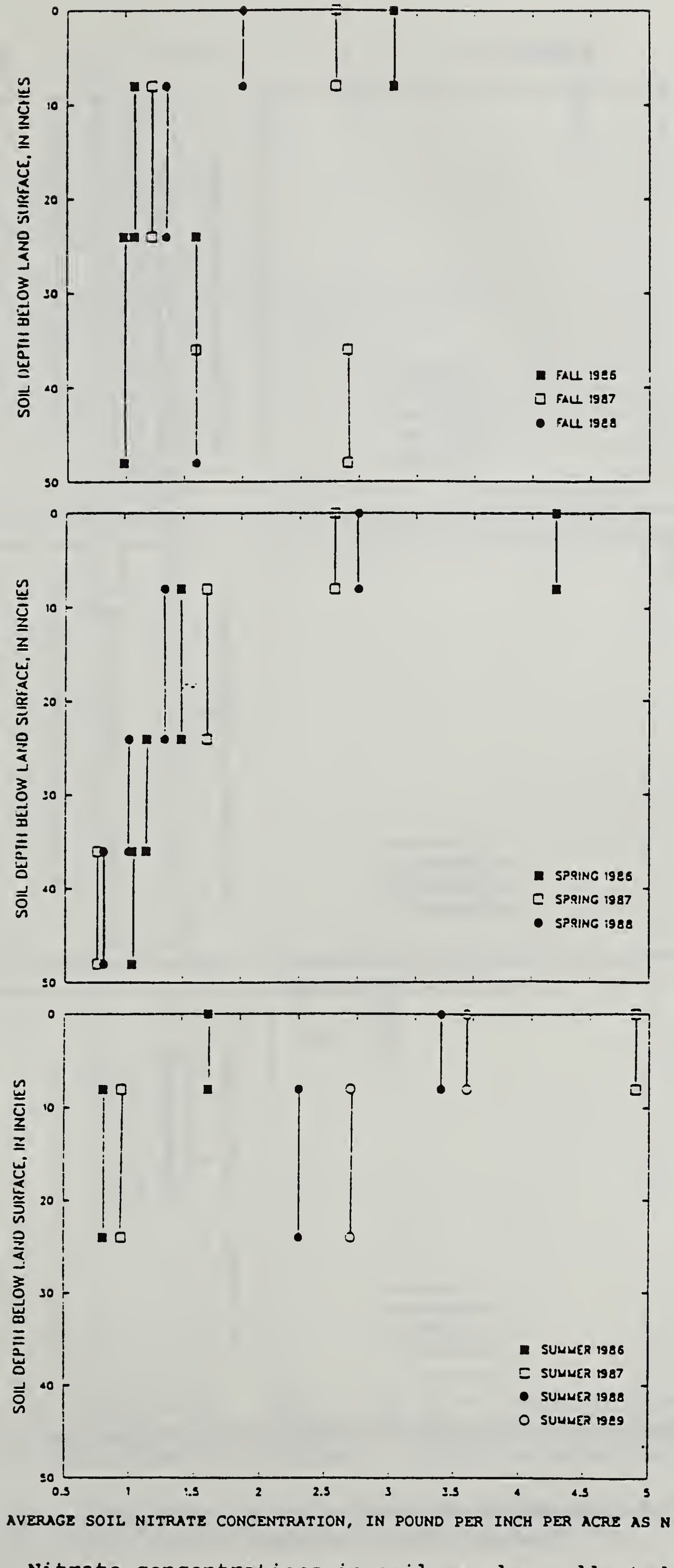


Figure 7.4-8.-- Nitrate concentrations in soil samples collected from Field 5 (planted in alfalfa) at Field-Site 1, 1986-1989.

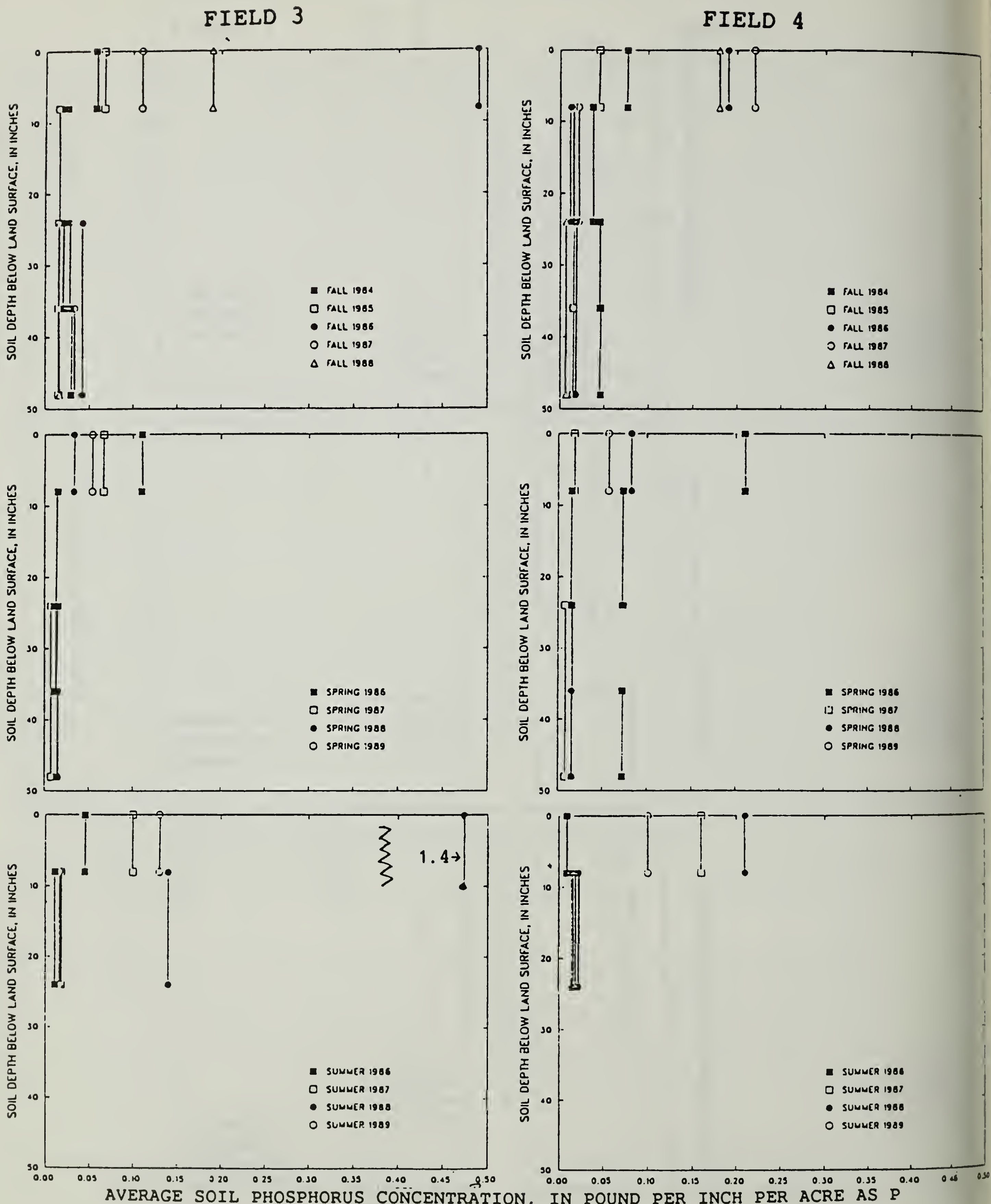


Figure 7.4-9.-- Phosphorus concentrations in soil samples collected from Fields 3 and 4 (planted in corn) at Field-Site 1, 1984-1989.

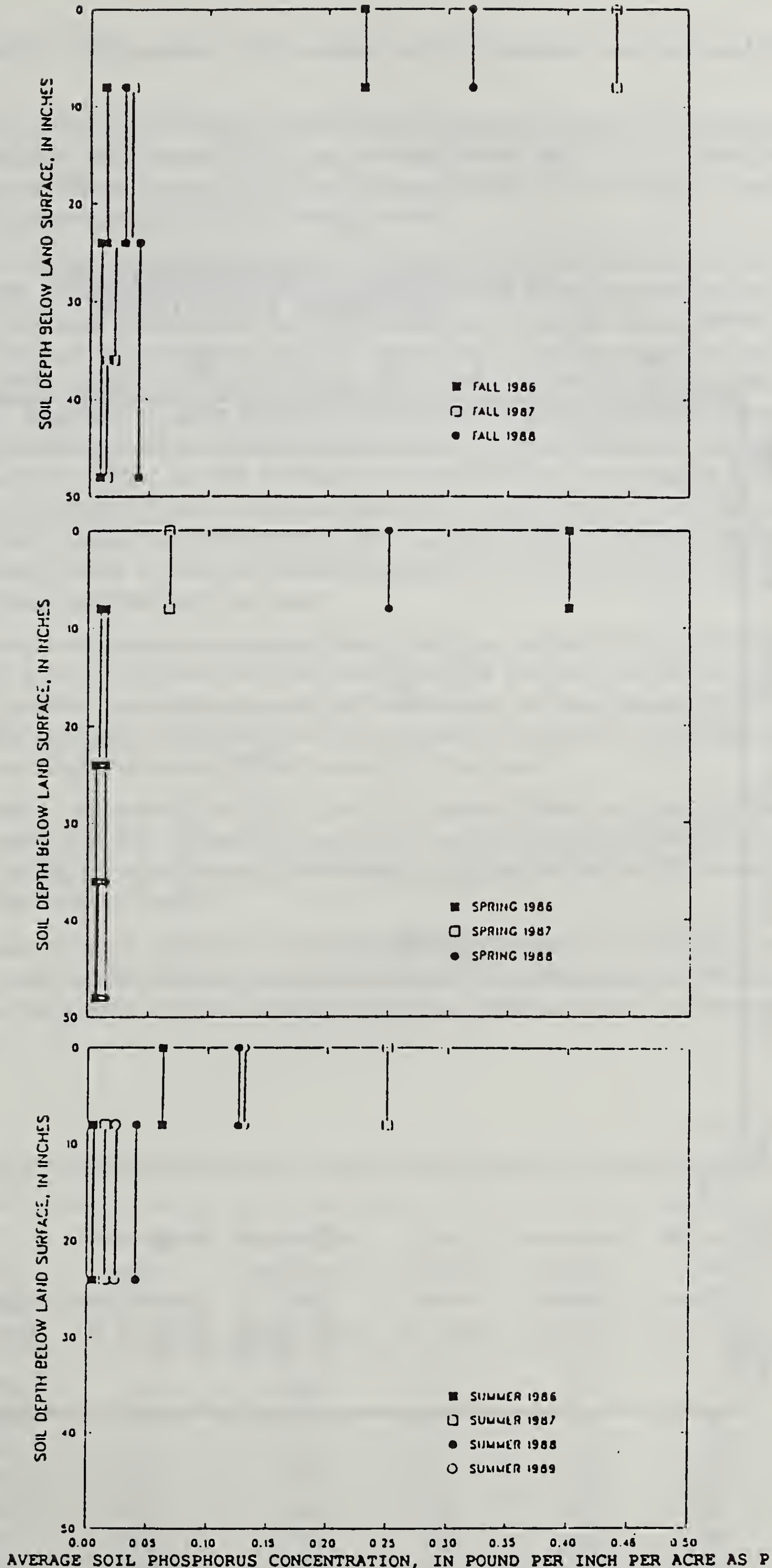


Figure 7.4-10.-- Phosphorus concentrations in soil samples collected from Field 5 (planted in alfalfa) at Field-Site 1, 1986-1989.

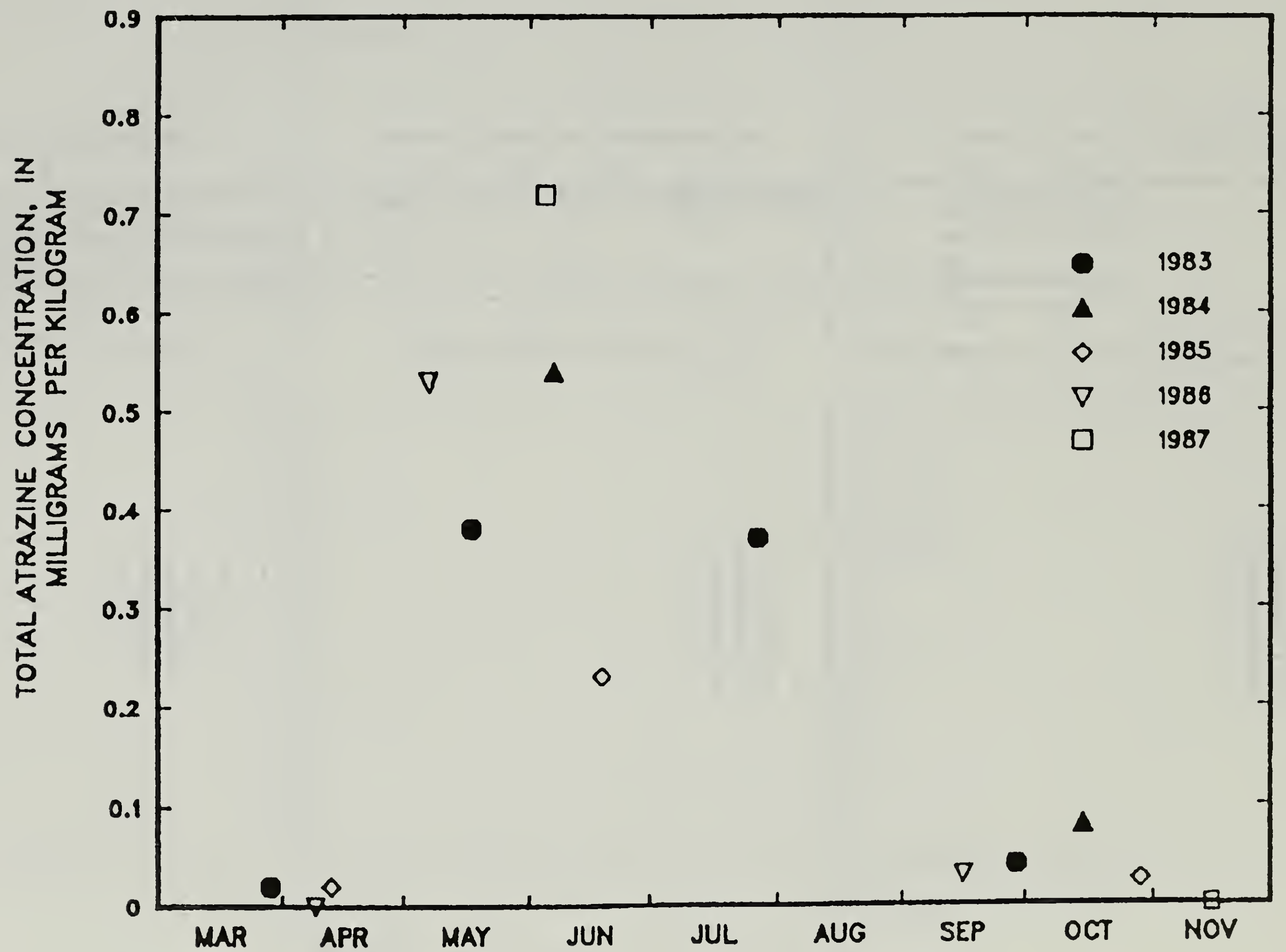


Figure 7.4-11.-- Concentration of atrazine in composite soil samples of the top two inches at Field-Site 1.

during Periods 1 (21 months), 2 (24 months), 3 (24 months), and 4 (10 months), was recorded 97, 58, 52, and 29 times, respectively.

During the post-BMP periods, runoff only occurred when storms were larger, and generally of longer durations and higher intensities than storms during the pre-BMP period (fig. 7.4-12). These changes were a result of terrace construction which changed the runoff characteristics. This change in character is most evident in the shape of the hydrographs for the different periods.

There was an obvious change in runoff from before to after terracing. Examples of "typical" before- and after-terracing hydrographs are shown in figure 7.4-13. During Period 1, before terracing, the hydrograph had numerous peaks of different sizes due to varying intensities of rainfall. Also, surface runoff from different parts of the field could be distinguished on the hydrograph: the lower part of the field peaked first, followed by subsequent peaks from both the alfalfa field which slowed runoff, and the upgradient cornfield. After terracing, retention of water behind the terraces and steady drainage through the pipe-outlets, masked multiple peaks regardless of precipitation intensity. The field between the gage and the first terrace was planted in corn the spring of 1985 (Period 2) and in alfalfa in the spring of 1986. During the summer of 1985, the initial hydrograph peak was associated with runoff from the corn field downgradient of the first terrace and initial outflow from the terraces. This was followed by a stepwise decline in stage as the terraces drained. During Period 3, when the field downgradient of the first terrace was established in alfalfa, the initial runoff peaks generally did not occur.

Small amounts of runoff were observed to drain through the pipe outlets for hours after the main bulk of the runoff discharged. This runoff, less than 0.01 cubic feet per second, was not measurable by the float/stage recorder and therefore was not accounted for in analysis of the data. Some immeasurable runoff also discharged during the pre-BMP monitoring, but for shorter time periods. Comparison between total runoff before and after terracing may be slightly influenced by this factor.

For Periods 1, 2, 3, and 4, respectively, 9.8, 15, 13, and 3.9 percent of the total precipitation discharged from the site as runoff (table 7.4-6). For the pre-BMP period, the percent runoff varied from 3 percent for the 9 month period of study in 1983 (January through September), to 13 percent for the 1984 water year. Annual variation was much less for Periods 2 and 3.

The discharge relation between Period 1 and the post-BMP periods was examined using several statistical techniques to better understand the cause for changes. The preliminary results of data analysis using summary statistics, regression analysis, covariate analysis, cluster analysis, and Mann-Whitney test are summarized below.

Table 7.4-6.--Discharge, suspended-sediment, and nutrient yields in runoff from Field-Site 1

Period	Water year	Total discharge (ft^3/acre)	Percent of total precipitation in runoff	Suspended sediment yield (tons/acre)	Total nitrogen yield (lb/acre)	Ammonia + organic (percent of total N)	Nitrite + nitrite (percent of total N)	Total phosphorus yield (lb/acre)
1	1983[1]	3,734	3.3	0.69	1.6	91	9	0.93
1	1984	28,568	13.2	10.4	12	92	8	6.7
2	1985	24,317	16.1	3.3	7.7	68	32	3.0
2	1986	17,859	13.8	.78	6.2	68	32	2.9
3	1987	18,851	11.2	.52	4.5	61	39	4.0
3	1988	21,788	14.5	1.0	9.3	64	36	3.8
4	1989[2]	5,692	3.9	.27	3.4	79	21	1.3

[1] January through September 1983.

[2] October 1988 through July 1989.

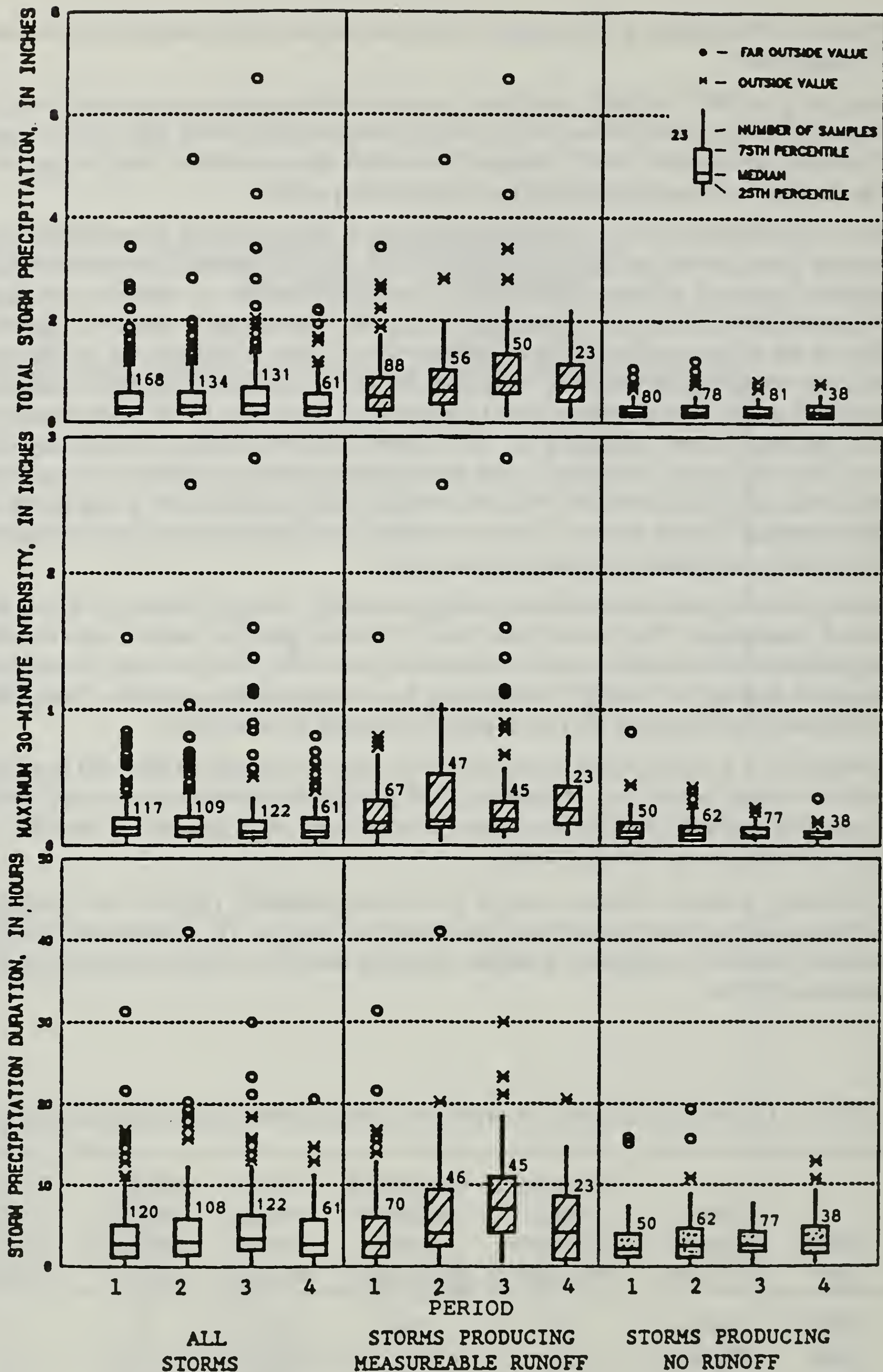


Figure 7.4-12.-- Total storm precipitation, maximum 30-minute intensity within each storm, and storm duration for all storms, storms producing runoff, and storms which did not produce runoff during Periods 1 (January 1983 through September 1984), 2 (October 1984 through September 1986), 3 (October 1986 through September 1988), and 4 (October 1988 through July 1989).

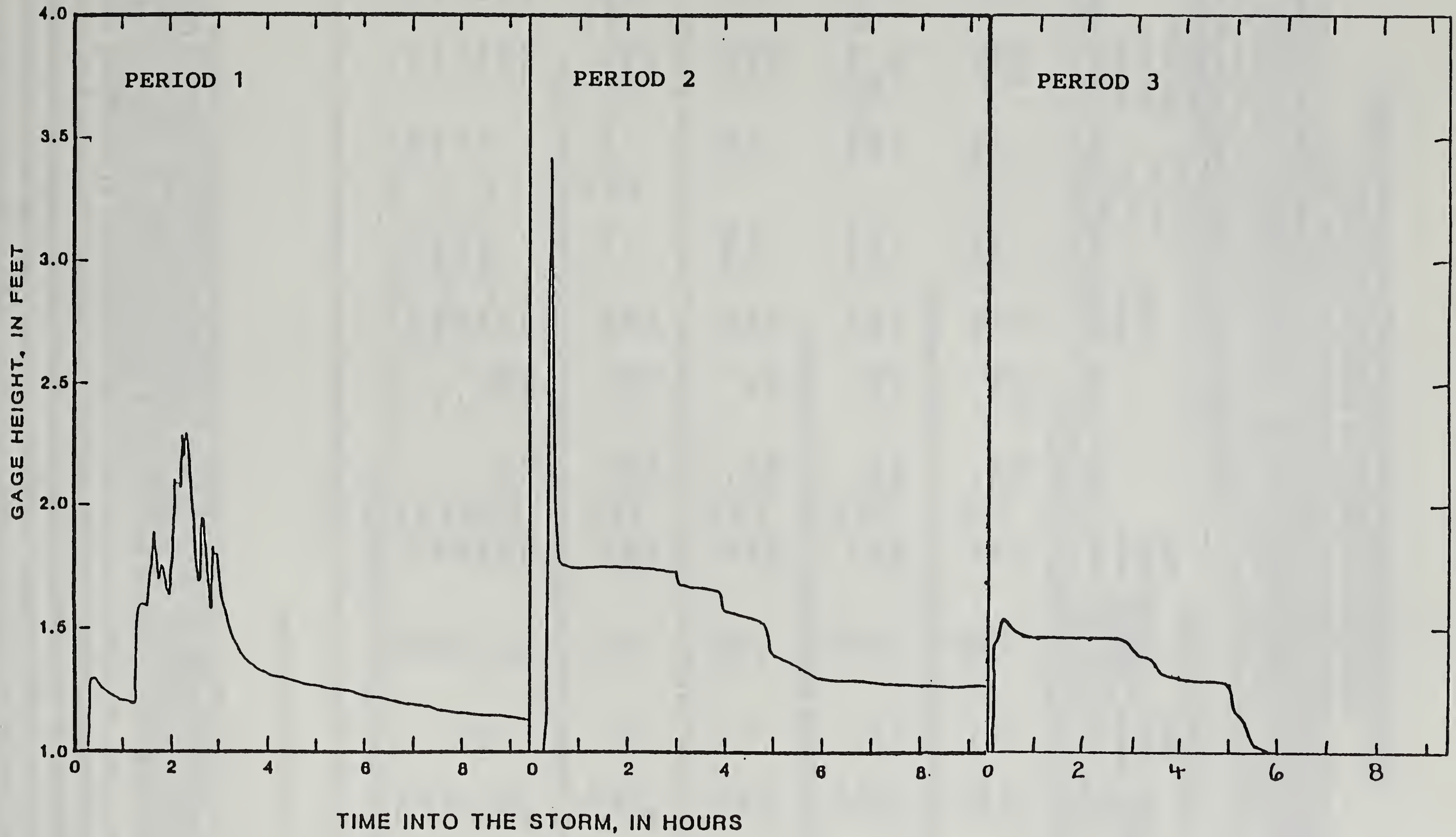


Figure 7.4-13--Hydrographs of runoff for a storm from Period 1 (June 24, 1984), Period 2 (July 31, 1985), and Period 3 (July 26, 1988) with similiar amounts of rainfall (0.65-0.80 inches) and similiar soil conditions.

Table 7.4-7.—Multiple-regression statistics of pre-BMP data for runoff variables as a function of precipitation and agricultural-activity variable

[ft^3, cubic feet; ft^3/s, cubic feet per second; DV, dependent variable used for the regression; NS, independent variable was entered as possible independent variable in stepwise regression, but did not contribute significantly to the regression equation; <, less than; --, not entered in regression; —, not applicable]

		Log of dependent variables			Coefficients and associated statistics for logs of independent variables								
Data set	Degrees of freedom[1]	Total runoff (ft^3)	Mean event discharge (ft^3/s)	Maximum discharge (ft^3/s)	Total precipitation (inches)	t-statistic	p-value	30-minute intensity (inches)	t-statistic	p-value	Total precipitation for 30 days prior to runoff (inches)	t-statistic	p-value
A (ALL RUNOFF EVENTS WITH MEASURED PRECIPITATION DATA)													
	59	DV	--	--	1.115	4.107	<0.001	NS	—	—	0.743	2.139	0.04
	59	--	DV	--	.455	3.026	.004	NS	—	—	.079	2.080	.05
	59	--	--	DV	NS	—	—	.801	3.526	<0.001	.972	3.259	.002
B (DATA SET A WITHOUT RUNOFF EVENTS OCCURRING ON FROZEN GROUND)													
	55	DV	--	--	1.535	8.035	<.001	NS	—	—	1.725	6.618	<.001
	55	--	DV	--	1.494	7.219	<.001	1.409	6.094	<.001	NS	—	—
	55	--	--	DV	NS	—	—	1.508	8.448	<.001	1.685	7.619	<.001
C (DATA SET B WITHOUT FIRST RUNOFF EVENT AFTER SPRING PLOWING)													
	54	DV	--	--	1.630	9.938	<.001	NS	—	—	1.606	7.184	<.001
	54	--	DV	--	.375	2.468	.02	1.254	7.410	<.001	1.188	6.898	<.001
	54	--	--	DV	NS	—	—	1.650	10.609	<.001	1.581	8.311	<.001
D (DATA SET C WITH RUNOFF EVENTS OCCURRING WHEN THERE WAS LESS THAN 10 PERCENT CROP COVER)													
	31	DV	--	--	1.518	7.128	<.001	NS	—	—	1.858	5.924	<.001
	31	--	DV	--	1.380	6.474	<.001	NS	—	—	1.380	7.058	<.001
	31	--	--	DV	NS	—	—	1.484	5.123	<.001	1.641	5.677	<.001
E (DATA SET C WITH RUNOFF EVENTS OCCURRING WHEN THERE WAS 10 TO 100 PERCENT CROP COVER)													
	22	DV	--	--	1.676	5.708	<.001	NS	—	—	1.204	3.505	.002
	22	DV	--	--	1.522	5.907	<.001	NS	—	—	.938	3.035	.007
	22	--	DV	--	NS	—	—	1.701	4.638	<.001	1.248	3.160	.005
	22	--	DV	--	NS	—	—	1.400	3.893	.001	.879	2.224	.04
	22	--	--	DV	NS	—	—	1.385	4.978	<.001	1.290	4.305	<.001
	22	--	--	DV	NS	—	—	1.135	4.275	<.001	.984	3.371	.004

[1] Degrees of freedom equal to number of storms minus one.

[2] R^2 adjusted for degrees of freedom and number of independent variables to allow comparison of regression models based on different sets of data.

[3] Calculated as described by Tasker (1978).

During the pre-BMP period, results from multiple-regression analyses suggested that total runoff was primarily controlled by total precipitation and antecedent soil moisture (estimated using total precipitation for 30 days prior to runoff event). The maximum instantaneous discharge was controlled primarily by precipitation intensity and antecedent soil moisture. A small amount of crop cover on corn acreage (estimated at as little as 10 percent) reduced total runoff and discharges by intercepting rainfall and increasing evapotranspiration (table 7.4-7). The pre-BMP data also showed that when the soil was frozen, nearly all the rainfall ran off, and when the ground was recently plowed, a large amount of rainfall or high intensity rainfall was required to produce runoff. With these two types of storms eliminated from the data base, regression analysis indicated the total amount of precipitation explained about 50 percent of the variability in total runoff (P.L. Lietman, U.S. Geological Survey, written commun., 1990).

Table 7.4-7.—Multiple-regression statistics of pre-BMP data for runoff variables as a function of precipitation and agricultural-activity variable

[ft^3, cubic feet; ft^3/s, cubic feet per second; DV, dependent variable used for the regression; NS, independent variable was entered as possible independent variable in stepwise regression, but did not contribute significantly to the regression equation; <, less than; –, not entered in regression; —, not applicable]

Coefficients and associated statistics for logs of independent variables									
Precipitation duration (hours)	t-statistic	p-value	Estimated crop cover on corn acreage (percent)	t-statistic	p-value	Intercept	Coefficient of determination (adjusted R^2)[2]	Standard error (log units)	Standard error percent (plus/minus)[3]
NS	—	—	–	—	—	3.122	0.28	0.812	548 85
NS	—	—	–	—	—	-.255	.17	.806	540 84
NS	—	—	–	—	—	-.224	.33	.682	381 79
NS	—	—	–	—	—	2.540	.66	.546	252 72
-0.748	4.938	<0.001	–	—	—	-1.041	.61	.484	205 67
NS	—	—	–	—	—	-.235	.71	.463	190 66
NS	—	—	–	—	—	2.675	.74	.465	192 66
NS	—	—	–	—	—	-.625	.76	.358	128 56
NS	—	—	–	—	—	-.042	.78	.395	148 60
NS	—	—	NS	—	—	2.465	.75	.484	205 67
-.669	4.031	<.001	NS	—	—	-.854	.73	.329	113 53
NS	—	—	NS	—	—	-.267	.71	.435	172 63
NS	—	—	–	—	—	2.996	.62	.440	175 64
NS	—	—	-.844	2.858	0.01	4.531	.72	.377	137 58
NS	—	—	–	—	—	-.485	.48	.444	178 64
NS	—	—	-.752	2.256	.04	.850	.57	.405	154 60
NS	—	—	–	—	—	.088	.55	.337	117 54
NS	—	—	-.624	2.536	.02	1.195	.65	.299	99 50

Results from multiple regression analysis also showed that the total runoff after terracing was controlled by the same factors—total precipitation and antecedent soil moisture—as total runoff before terracing. However, the measured mean and maximum storm discharges at the gage were controlled by the pipe-outlet dynamics, rather than climatological factors.

Analysis of covariance of the logarithm of total storm runoff as a function of the logarithm of total storm precipitation for Periods 1 through 4 for all storms which produced runoff except those occurring on frozen ground indicated that using Period 1 as the base, runoff as a function of total precipitation was not significantly different during Periods 3 and 4, but was proportionally greater during Period 2 (fig 7.4-14 and table 7.4-8). Figure 7.4-14 also shows that the small amounts of precipitation (less than 0.10 in.) did not

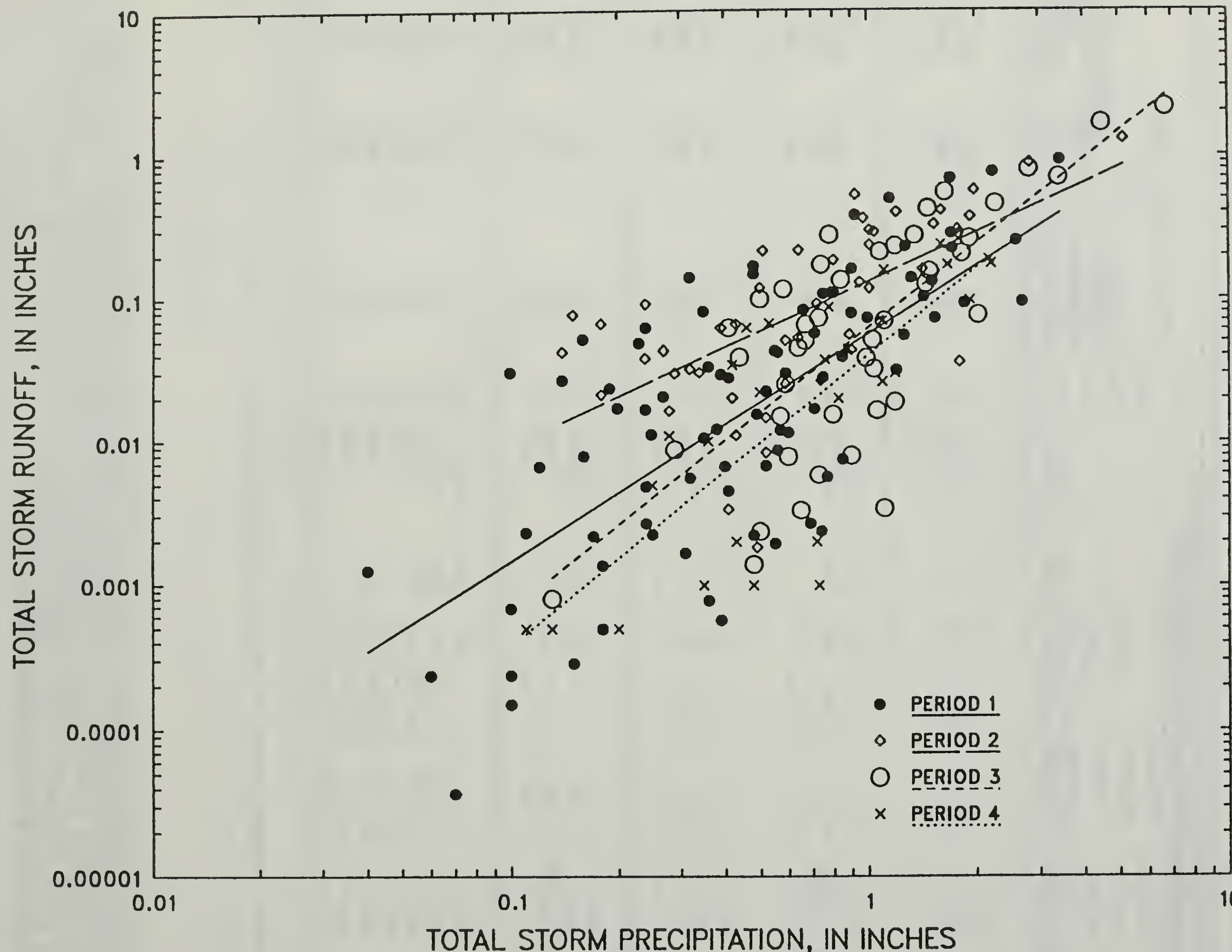


Figure 7.4-14.-- Total storm runoff as a function of total precipitation for all storms except storms on frozen ground for Periods 1 (January 1983 through September 1984), 2 (October 1984 through September 1986), 3 (October 1986 through September 1988), and 4 (October 1988 through July 1989). (Regression statistics are listed in Table 7.4-8).

produce runoff during the post-BMP period. However, visual examination of the graphical data showed that nearly all the data for Period 2 plotted within the variability of data for Period 1 (fig. 7.4-14). So, no conclusive evidence of differences between periods exist. Similar analysis using multiple regression of the total discharge as a function of the log of total precipitation and the log of antecedent soil moisture yielded similar results.

Pre-BMP data analysis showed that in addition to total storm precipitation and precipitation duration antecedent soil moisture condition, precipitation intensity, and crop cover also affected storm discharge. Therefore, in order to make a comparison of runoff characteristics from Period 1 to the post-BMP periods, the data were separated by these characteristics using cluster analysis. Eight clusters were defined. Five clusters included all but 7 of the storms. A characterization of the clusters is given in table 7.4-9 and figure 7.4-15 shows data from 5 of the clusters. (For the cluster analysis, a factor from 1 to 4 was used based on estimated crop cover: (1) <15 percent, (2) 15 to 49 percent, (3) 50 to 85 percent, and (4) >85 percent.) In this analysis, storms occurring on frozen ground were eliminated from the data sets and runoff was set at zero when no runoff was measured for a storm.

Table 7.4-10 summarizes changes that were detected for four clusters using the Mann-Whitney test for all storms and storms producing runoff. Cluster 3 was not included because there was an insufficient number of storms for comparison in Periods 2 and 3. Clusters 2, 4, and 5 were not included because they represented too few storms for any period. The test results in table 7.4-10 show that for clusters 1 and 7, clusters containing small storms, fewer storms produced runoff during the post-BMP periods than during the pre-BMP period. For Cluster 1 storms, there was a significant decrease in total storm discharge (on a per acre basis) from storms occurring in Period 1 to those occurring in Period 2, Period 3, or the entire post-BMP period. For Cluster 7, there was a significant decrease in total storm discharges from storms in Period 1 to those in Period 3 and the whole post-BMP period. Terracing decreased runoff by changing the surface slopes and increasing surface storage. Nearly all the storms in Clusters 6 and 8, which produced about 5 times greater precipitation than storms in Clusters 1 and 7, produced runoff during all the periods. The total storm discharge for storms in Clusters 6 and 8 did not change from Period 1 to Period 3.

In summary, preliminary data analysis showed that the terraces reduced runoff from small storms (generally less than 0.4 in.) and, in effect, increased the threshold at which runoff occurs and no overall effect on runoff quantity. The terrace BMP had no significant effect on runoff quantity during larger storms.

Annual suspended-sediment nutrient yields in runoff from Field-Site 1 (calculated as described in section 6.9.7.2) are shown in table 7.4-6. Total yields for the 79-month study period averaged 2.6 tons per acre per year for suspended sediment, 6.8 pounds per acre per year for nitrogen, and 3.3 pounds per acre per year for phosphorus. The 1984 annual suspended-sediment yield exceeded the erosion factor T of 4 (ton/acre)/yr recommended for the site by the U.S. Soil Conservation Service. The suspended-sediment yield was substantially less than T for all the years after terrace installation and after a year of stabilization (table 7.4-6). The annual yields of total nitrogen and phosphorus for the post-BMP period were within the range of yields for the pre-BMP period. However, during the pre-BMP period (Period 1), less than 10 percent of the annual total nitrogen yield was nitrate plus nitrite, and over 90 percent was ammonia + organic nitrogen; during post-BMP Periods 2 and 3, 32 to 39 percent of the annual total nitrogen yield was nitrate plus nitrite (table 7.4-6). The nutrient yields in runoff represent about 2.4 and 4.6 percent of the nitrogen and phosphorus, respectively, applied to the site.

The distribution of total storm yields and mean storm concentrations for each constituent and each period is shown in figure 7.4-16. The boxplots summarize the values and ranges of the data for the study. The extreme sediment yields and mean storm concentrations found in Period 1 prior to terracing did not occur during the post-BMP periods. Similar diminished extremes in the nutrient yields during the post-BMP periods did not occur. However, the extreme values of storm concentrations of total ammonia plus organic nitrogen, total nitrogen, and total phosphorus decreased from Period 1 to the post-BMP periods and extreme values of mean total nitrate plus nitrite concentration increased.

In the pre-BMP period, it was found that runoff from storms on frozen ground and the first storms after plowing responded differently than runoff from other storms. Mean concentrations and loads of suspended-sediment were low--less than 700 mg/L and less than 0.40 tons, respectively (table 7.4-11), for

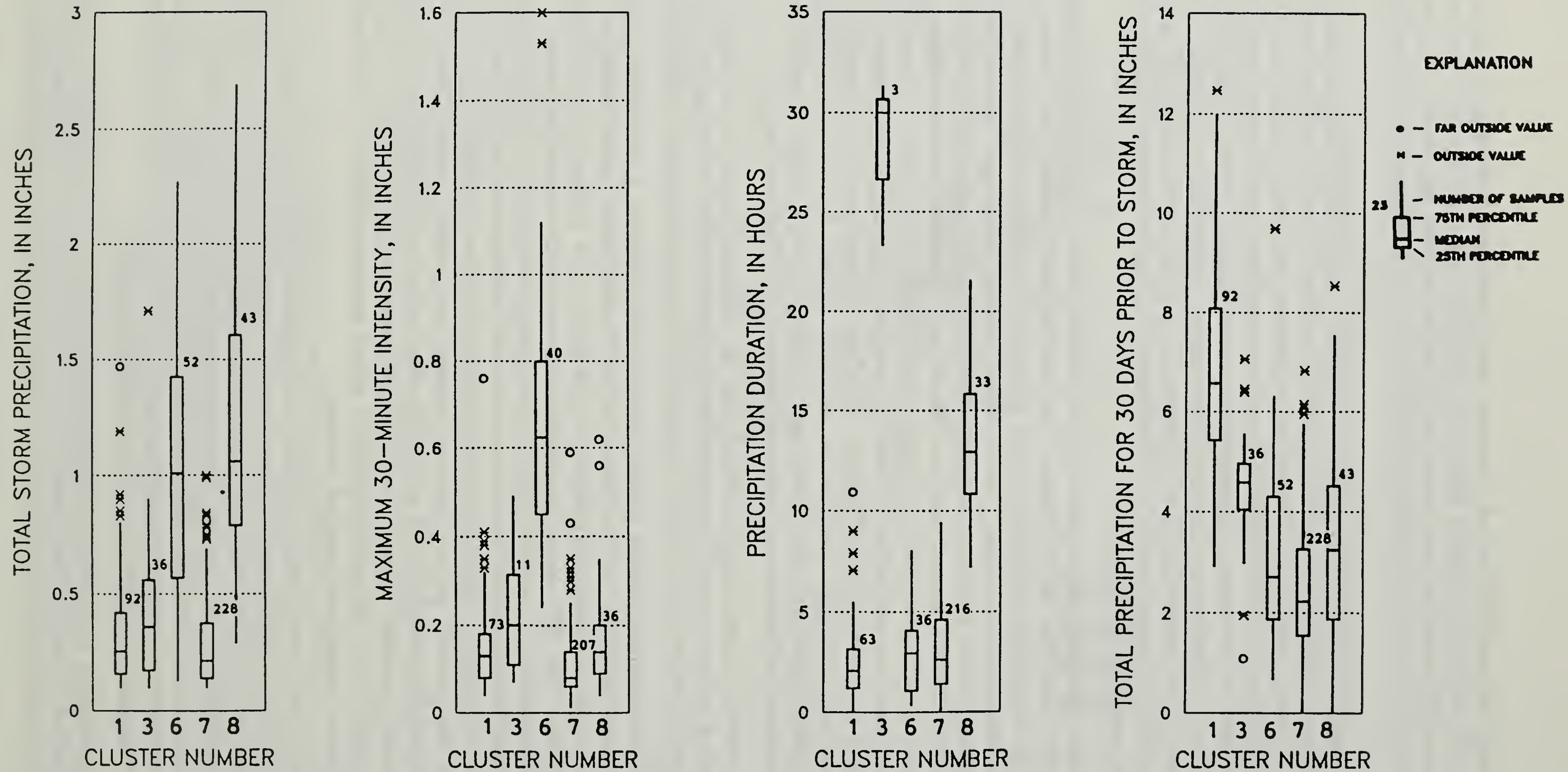


Figure 7.4-15.-- Distribution of precipitation data used to group similar type storms into clusters described in Table 7.4-9.

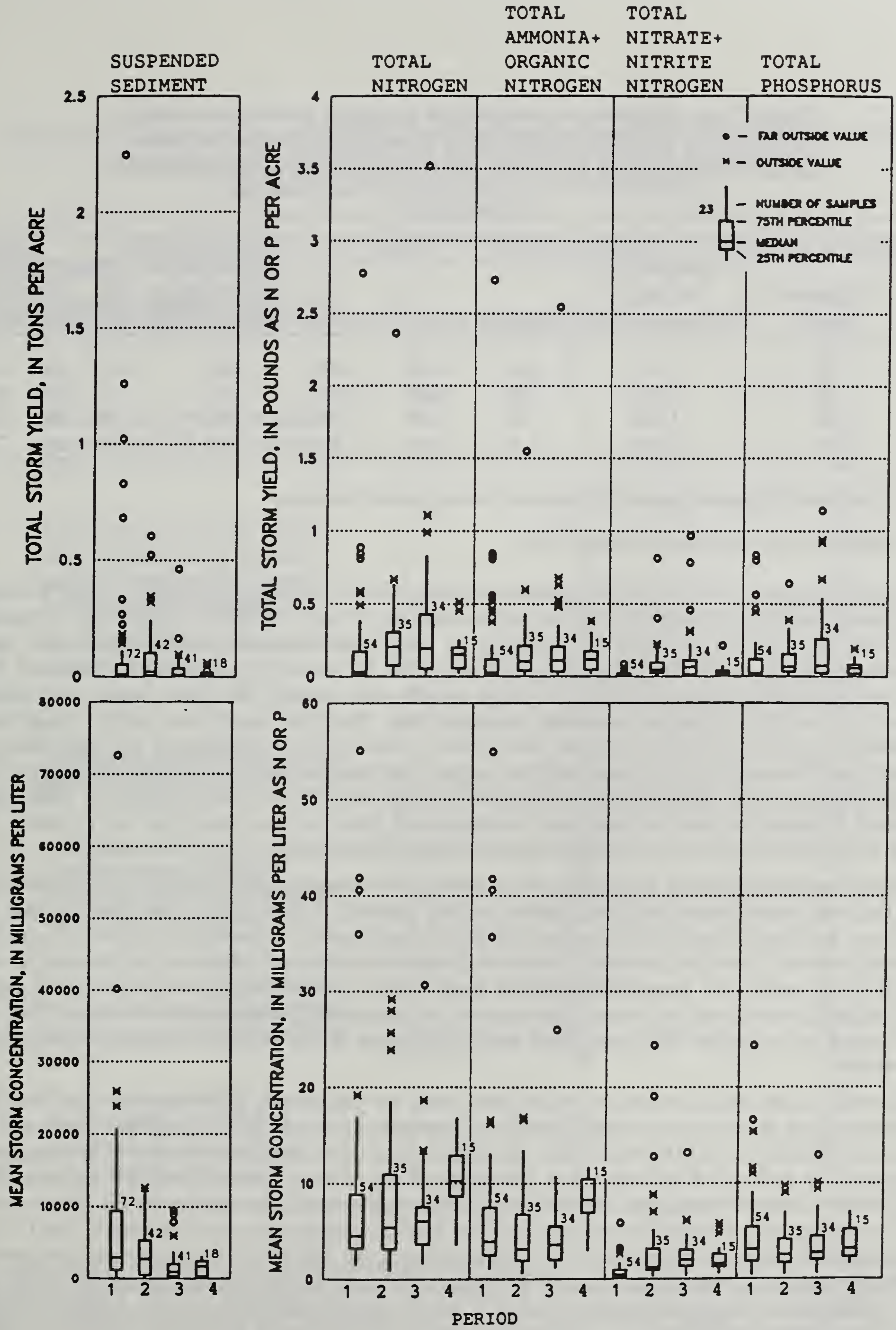


Figure 7.4-16.-- Distribution of suspended-sediment and nutrient yields and mean storm concentrations in runoff from Field-Site 1 for Periods 1 (January 1983 through September 1984), 2 (October 1984 through September 1986), 3 (October 1986 through September 1988), and 4 (October 1988 through July 1989).

Table 7.4-8.--Regression statistics for the log of total storm runoff, in inches, as a function of the log of storm precipitation, in inches, for all storms in each period except those occurring on frozen ground

[<, less than]

Period	Degrees of freedom	Coefficient of the log of total precipitation	t-statistic	p-value	Intercept	Coefficient of determination (Adjusted R^2)[1]	Standard error: Log units	Standard error: Percent[2] Plus	Standard error: Percent[2] Minus
1	84	1.578	8.47	<0.001	-1.254	0.46	0.70	337	77
2	49	1.164	5.92	<.001	-8.74	.41	.47	209	68
3	43	1.960	7.41	<.001	-1.211	.46	.54	255	72
4	27	2.016	6.51	<.001	-1.403	.60	.56	280	74

[1] Coefficient of determination (R^2) adjusted for degrees of freedom.

[2] Calculated as described by Tasker (1978).

five of the six storms occurring when the ground was frozen. For the sixth storm (February 1984), the mean suspended-sediment concentration and load were 6,800 mg/L and 0.56 tons, respectively. A shallow surface thaw probably increased the availability of suspended sediment during this storm. Total-phosphorus loads from five runoff events in 1984 accounted for about 45 percent of the estimated 1984 water year total-phosphorus load. Four of these events were among the same events contributing 60 percent of the 1984 estimated suspended-sediment load. The fifth runoff event with a large total-phosphorus load was a winter snowmelt storm that accounted for 5.8 percent of the total Period 1 estimated load.Three of the five events with the largest total nitrogen loads, 13 to 61 lb, during the pre-BMP study period were rain-on-snow or snowmelt events (table 7.4-11). The February 3, 1983, event transported 20 percent of the total estimated nitrogen load from the site during the study period. The nitrogen in runoff for this event was predominantly dissolved ammonium plus organic nitrogen.

During the pre-BMP period, the greatest mean suspended-sediment concentrations and loads occurred during the first intense thunderstorms following spring plowing. Soil loosened from plowing, and soil plowed over previously formed deep gullies, provided a large source of suspended sediment for runoff. Two runoff events of this type accounted for about 30 percent of the total estimated load leaving the site during the 1984 water year. Suspended-sediment loads from 5 storms (10 percent of the sampled runoff events, including runoff from the two sampled storms just discussed, two thunderstorms in July 1984, and a 3.4-in. storm in December 1983) comprised nearly 60 percent of the 1984 water year total suspended-sediment load.

All storms except those on frozen ground were used for preliminary data analysis. Graphical and regression analysis of the total constituent yields as a function of total storm discharge was performed for each of the Periods (figs. 7.4-17 through 7.4-21 and table 7.4-12). These analyses were used to investigate the relation between yields and discharge and differences in the relation between pre-BMP and post-BMP periods over the range of discharge. Suspended-sediment yields were lower during Period 3 than during Period 1 after terraces stabilized for two years and the field downslope from the first terrace (Field 1 - fig. 7.4-3) was stabilized with alfalfa (fig. 7.4-17). This result was expected and was the primary purpose for installing the terraces at the site and for the SCS recommendation to plant alfalfa downslope of the first terrace. Analysis of covariance indicates that the runoff carried proportionally less sediment during Periods 2 and 4 than during Period 1. Analysis of covariance also showed a statistically significant change between both the intercept and slope of the regression lines for Period 1 and Period 3. Graphical analysis shows that small storms carried about the same amount of sediment during Period 1 and Period 3, but large storms carried much less sediment during Period 3 than during Period 1 (fig. 7.4-17).

Table 7.4-9.--General characteristics of storms, by cluster, and percent of total rainfall, by period, represented by the cluster (all storms on frozen ground were excluded from the data set prior to clustering)

Cluster	Characteristics	Period	Number of storms	Percent of total rainfall
5	Summer showers on moist soil with crop cover	1	31	11
		2	26	10
		3	21	10
		4	16	11
6	Three large storms throughout the year with 3.4 to 5.1 inches of rain	1	1	3.8
		2	1	6.6
		3	1	3.9
		4	0	0
7	Typical spring and fall all day rains generally with 0.2 to 0.6 inches of precipitation on soil with little crop coverage	1	22	9.4
		2	2	.3
		3	2	1.7
		4	10	13
8	One large September storm with 6.7 inches of rain	1	0	0
		2	0	0
		3	1	7.7
		4	0	0
9	Three large summer storms with 2.8 to 4.5 inches of rain	1	0	0
		2	1	3.6
		3	2	8.3
		4	0	0
10	Thunderstorms occurring predominantly in the summer on soil with crop cover	1	18	18
		2	20	27
		3	10	14
		4	4	15
11	Very small storms throughout the year on dry soil, most storms occurring on soil with little crop cover	1	67	22
		2	63	21
		3	73	24
		4	25	16
12	Typical spring and fall all day rains generally with 0.8 to 1.6 inches of precipitation on soil with little crop cover	1	15	21
		2	11	7
		3	12	16
		4	26	9

Total nitrate plus nitrite yields as a function of total storm discharge for each post-BMP period were different than the yields for Period 1 (fig. 7.4-18). Analysis of covariance indicated that proportionally more nitrate was carried in storm runoff throughout the post-BMP periods than during Period 1 storms.

The only other significant change detected were significantly higher yields of ammonia + organic nitrogen (fig. 7.4-19) and of total nitrogen (fig. 7.4-20) between Period 1 and Period 4. However, Period 4 represented a smaller time period (10 months) with fewer storms than Period 1 (21 months). Thus interpretation of the data was limited.

Table-7.4-10.--Summary of (table 7.4-9 and fig. 7.4-15) Mann-Whitney test results comparing within clusters total discharges, mean storm nutrient concentrations, and total storm yields between Period 1 (1983-84) and the entire post-BMP period (1985-89), between Periods 1 and 2 (1985-86), and between Periods 1 and 3 (1987-88), storms on frozen ground excluded

[↑, statistically significant increase; ↓, statistically significant decrease; ↔, no statistically significant change; (90), significant at the 90 percent confidence interval; (95), significant at the 95 percent confidence interval; n, number of storms; mg/L, milligrams per liter; ft^3/acre, cubic feet per acre; lb/acre, pound per acre]

		Cluster 1			Cluster 6			Cluster 7			Cluster 8		
		Period 1-post-BMP	Period 1-Period 2	Period 1-Period 3	Period 1-post-BMP	Period 1-Period 2	Period 1-Period 3	Period 1-post-BMP	Period 1-Period 2	Period 1-Period 3	Period 1-post-BMP	Period 1-Period 2	Period 1-Period 3
All storms[1]	Total discharge yield	↓(95)	↓(95)	↓(90)	↑(95)	↑(95)	↔	↓(95)	↔	↓(95)	↔	↑(90)	↔
	(ft^3/acre) n	31/61	31/24	31/21	18/34	18/20	18/10	67/161	67/63	67/73	15/28	15/7	15/12
Storms which produced runoff	Total discharge yield	↔	↔	↑(90)	↑(95)	↑(95)	↔	↑(95)	↑(95)	↔	↔	↔	↔
	(ft^3/acre) n	21/21	21/5	21/7	13/31	13/18	13/9	26/27	26/16	26/10	13/26	13/7	13/12
	Suspended-sediment yield	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↓(95)
	(tons/acre) n	19/12	19/4	19/7	9/28	9/17	9/8	22/15	22/8	22/6	7/24	7/7	7/10
	Total phosphorus yield	↔	↔	↔	↔	↔	↔	↑(95)	↑(95)	↑(90)	↔	↔	↔
	(lb/acre as P) n	12/12	12/4	12/7	8/25	8/15	8/7	17/10	17/6	17/3	6/18	6/5	6/7
	Total nitrogen yield	↑(95)	↑(95)	↑(90)	↔	↔	↔	↑(95)	↑(95)	↑(90)	↔	↔	↔
	(lb/acre as N) n	12/12	12/4	12/7	8/25	8/15	8/7	17/10	17/6	17/3	6/18	6/5	6/7
	Total ammonia + organic nitrogen yield	↑(95)	↑(95)	↔	↔	↔	↔	↑(95)	↑(95)	↔	↔	↔	↔
	(lb/acre as N) n	12/12	12/4	12/7	8/25	8/15	8/7	17/10	17/6	17/3	6/18	6/5	6/7
	Total nitrate + nitrite yield	↑(95)	↑(95)	↑(95)	↑(95)	↑(90)	↑(90)	↑(95)	↑(95)	↑(95)	↑(95)	↑(95)	↑(90)
	(lb/acre as N) n	12/12	12/4	12/7	8/25	8/15	8/7	17/10	17/6	17/3	6/18	6/5	6/7
Storms which produced runoff	Mean suspended-sediment concentration	↔	↔	↔	↓(95)	↓(90)	↓(95)	↓(95)	↓(95)	↓(95)	↓(95)	↔	↓(95)
	(mg/L) n	19/12	19/4	19/7	9/28	9/17	9/8	22/15	22/8	22/6	7/24	7/7	7/10
	Mean total phosphorus concentration	↔	↔	↔	↓(90)	↓(90)	↔	↔	↔	↔	↔	↔	↔
	(mg/L as P) n	12/12	12/4	12/7	8/25	8/15	8/7	17/10	17/6	17/3	6/18	6/5	6/7
	Mean total nitrogen concentration	↑(95)	↑(95)	↑(90)	↔	↔	↔	↔	↔	↔	↑(90)	↔	↑(90)
	(mg/L as N) n	12/12	12/4	12/7	8/25	8/15	8/7	17/10	17/6	17/3	6/18	6/5	6/7
	Mean ammonia + organic nitrogen concentration	↑(95)	↑(95)	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔
	(mg/L as N) n	12/12	12/4	12/7	8/25	8/15	8/7	17/10	17/6	17/3	6/18	6/5	6/7
	Mean nitrate + nitrite concentration	↑(95)	↑(95)	↑(95)	↑(95)	↑(95)	↑(95)	↑(95)	↔	↑(95)	↑(95)	↑(95)	↑(95)
	(mg/L as N) n	12/12	12/4	12/7	8/25	8/15	8/7	17/10	17/6	17/3	6/18	6/5	6/7

[1]Total and mean discharge set equal to zero if no runoff.

Table 7.4-11.--Comparison of precipitation, runoff, and nutrient and suspended-sediment concentration and load data for runoff from rainstorms occurring on snow-covered frozen ground, and other runoff events, January 1983 through September 1984

[ft^3, cubic foot; mg/L, milligram per liter; lb, pound; <, less then; --, not applicable; –, no data]

				Total nitrogen as nitrogen			Total phosphorus as phosphorus			Suspended sediment		
Date	Precipi-tation (inches)	Runoff (inches)	Runoff (ft^3)	Mean event concentration (mg/L)	Maximum event concentration (mg/L)	Load (lb)	Mean event concentration (mg/L)	Maximum event concentration (mg/L)	Load (lb)	Mean event concentration (mg/L)	Maximum event concentration (mg/L)	Load (tons)
January 23, 1983	1.47	0.09	7,542	–	–	–	–	–	–	151	1,190	0.036
January 24, 1983	.00	.00	149	–	–	–	–	–	–	316	872	.002
January 24, 1984	.29	.23	18,700	11	22	13	0.80	1.2	0.93	24	77	.014
January 27 1984	.00	.09	7,060	41	52	18	2.7	6.7	1.2	658	770	.14
February 3, 1984	.25	.72	58,100	17	65	61	2.7	4.3	9.8	222	380	.40
February 11, 1984	.11	.03	2,660	3.7	5.6	.64	24	41	4.1	6,760	13,000	.56
ALL 50 OTHER RUNOFF EVENTS SAMPLED FOR NUTRIENTS												
Minimum	.06	<.01	19	1.5	2.2	.005	.45	.55	.002	–	–	–
Maximum	3.43	.92	73,500	55	81	20	17	23	18	–	–	–
Median	.48	.03	2,200	4.4	8.1	.70	3.2	5.6	.46	–	–	–
ALL 66 OTHER RUNOFF EVENTS SAMPLED FOR SUSPENDED SEDIMENT												
Minimum	.06	<.01	19	–	–	–	–	–	–	230	550	<.00
Maximum	3.43	.92	73,500	–	–	–	–	–	–	72,600	137,000	49.7
Median	.50	.03	2,300	–	–	–	–	–	–	3,000	6,440	.23

Table 7.4-12.--Regression statistics for the log of suspended-sediment yield, in tons per acre, and the log of total nutrient yield, in pounds as N or P per acre, as a function of the log of total runoff, in cubic feet per acre for all storms occurring during each study period except for storms on frozen ground

[<, less than]

Period[1]	Dependent variable	Degrees of freedom	Regression coefficient: Log of total runoff	t-statistic	p-value	Intercept	Coefficient of determination (Adjusted R^2)[2]	Standard error of estimates: Log units	Standard error of estimates: In percent[3] (plus/minus)	
1	Suspended sediment	65	1.239	15.47	<0.001	-4.391	0.82	0.495	213	68
2	Suspended sediment	37	.886	5.27	<.001	-3.898	.42	.573	274	73
3	Suspended sediment	34	.878	7.13	<.001	-4.143	.60	.491	210	68
4	Suspended sediment	16	.676	2.66	.018	-3.658	.28	.406	155	61
1	Total nitrogen	49	.942	16.85	<.001	-3.379	.85	.341	119	54
2	Total nitrogen	31	.843	7.33	<.001	-3.005	.63	.370	134	57
3	Total nitrogen	27	.866	12.21	<.001	-3.063	.85	.259	82	45
4	Total nitrogen	13	.792	6.24	<.001	-2.727	.74	.194	56	36
1	Total ammonium plus organic nitrogen	49	.948	15.77	<.001	-3.470	.83	.367	133	57
2	Total ammonium plus organic nitrogen	31	.949	7.66	<.001	-3.504	.65	.398	150	60
3	Total ammonium plus organic nitrogen	27	.876	11.60	<.001	-3.295	.83	.276	89	47
4	Total ammonium plus organic nitrogen	13	.783	6.08	<.001	-2.808	.73	.196	57	36
1	Total nitrate plus nitrite	49	1.006	14.23	<.001	-4.528	.80	.431	170	63
2	Total nitrate plus nitrite	31	.708	4.91	<.001	-3.213	.43	.464	191	66
3	Total nitrate plus nitrite	27	.869	10.59	<.001	-3.553	.80	.300	100	50
4	Total nitrate plus nitrite	13	.794	4.17	.001	-3.469	.56	.290	95	49
1	Total phosphorus	49	1.036	16.65	<.001	-3.799	.85	.379	139	58
2	Total phosphorus	31	.859	10.32	<.001	-3.403	.77	.267	85	46
3	Total phosphorus	27	.925	12.90	<.001	-3.438	.86	.262	83	45
4	Total phosphorus	13	.886	6.25	<.001	-3.390	.74	.216	64	39

[1] Period 1, January 1983 through September 1984; Period 2, October 1984 through September 1986; Period 3, October 1986 through September 1988; Period 4, Oct ober 1988 through July 1989.

[2] R^2 adjusted for degrees of freedom to allow more valid comparison between seasons.

[3] Calculated as described by Tasker (1978).

To better understand the impact of terracing on runoff quality, the suspended-sediment and nutrient data were compared within the clusters as described earlier in this section (fig. 7.4-15 and table 7.4-9).

For storms in clusters 6, 7, and 8, mean suspended-sediment concentrations decreased from Period 1 to Period 3 and from Period 1 to the entire post-BMP period (tables 7.4-10 and 7.4-13). The terraces reduced runoff energy and thus the ability to transport sediment, and pooling in terraces allowed time for deposition of suspended material before the runoff discharged through the pipe-outlet. For storms in Cluster 1, which contained the smallest storms, no significant change was detected in suspended-sediment concentrations from Period 1 to Period 3 using the Mann-Whitney test. However, graphical examination of the data within Cluster 1 shows that suspended sediment yields per unit of discharge were generally larger

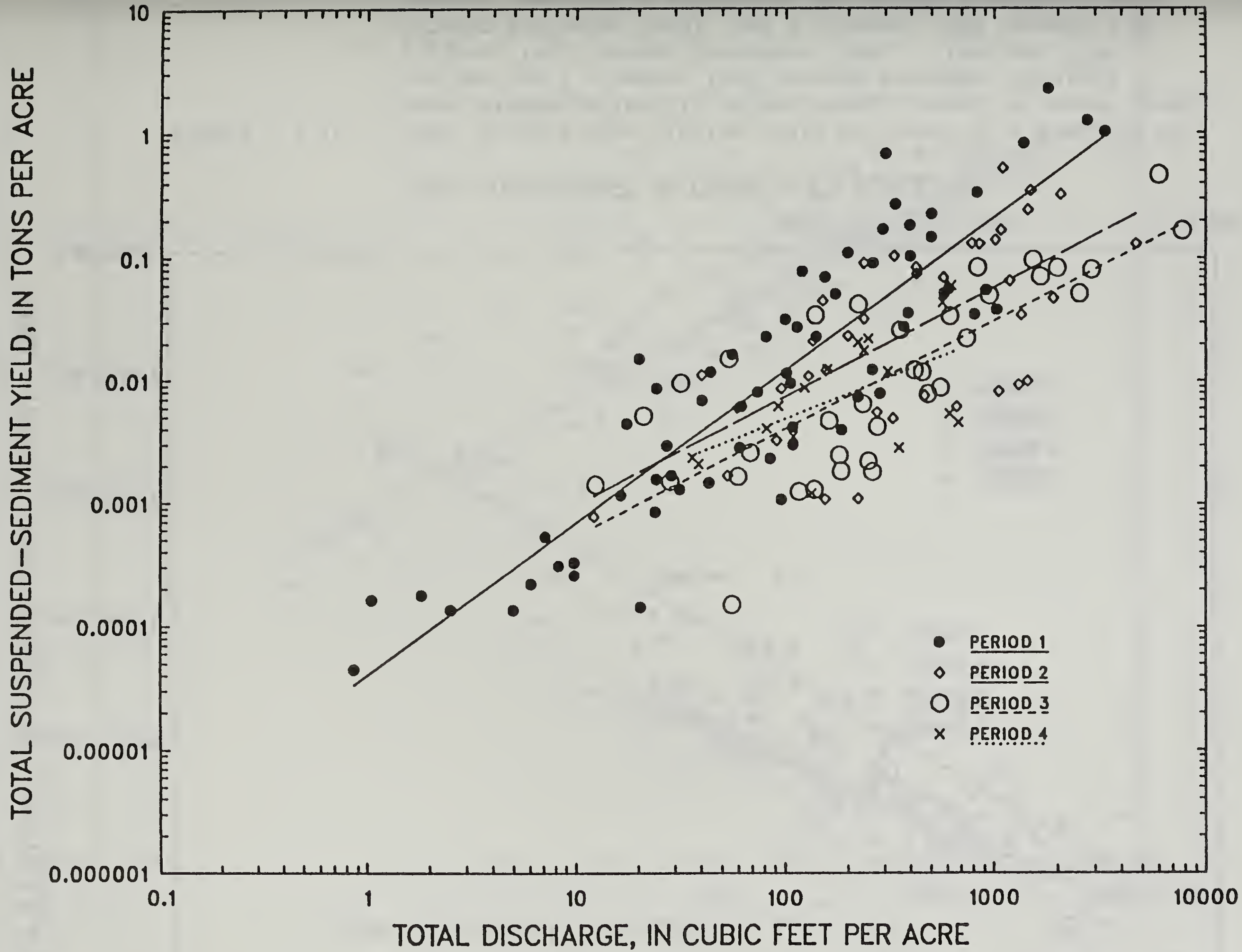


Figure 7.4-17.-- Total suspended-sediment yield in runoff as a function of total discharge for all storms except storms on frozen ground for Periods 1 (January 1983 through September 1984), 2 (October 1984 through September 1986), 3 (October 1986 through September 1988), and 4 (October 1988 through July 1989). (Regression statistics are listed in Table 7.4-13).

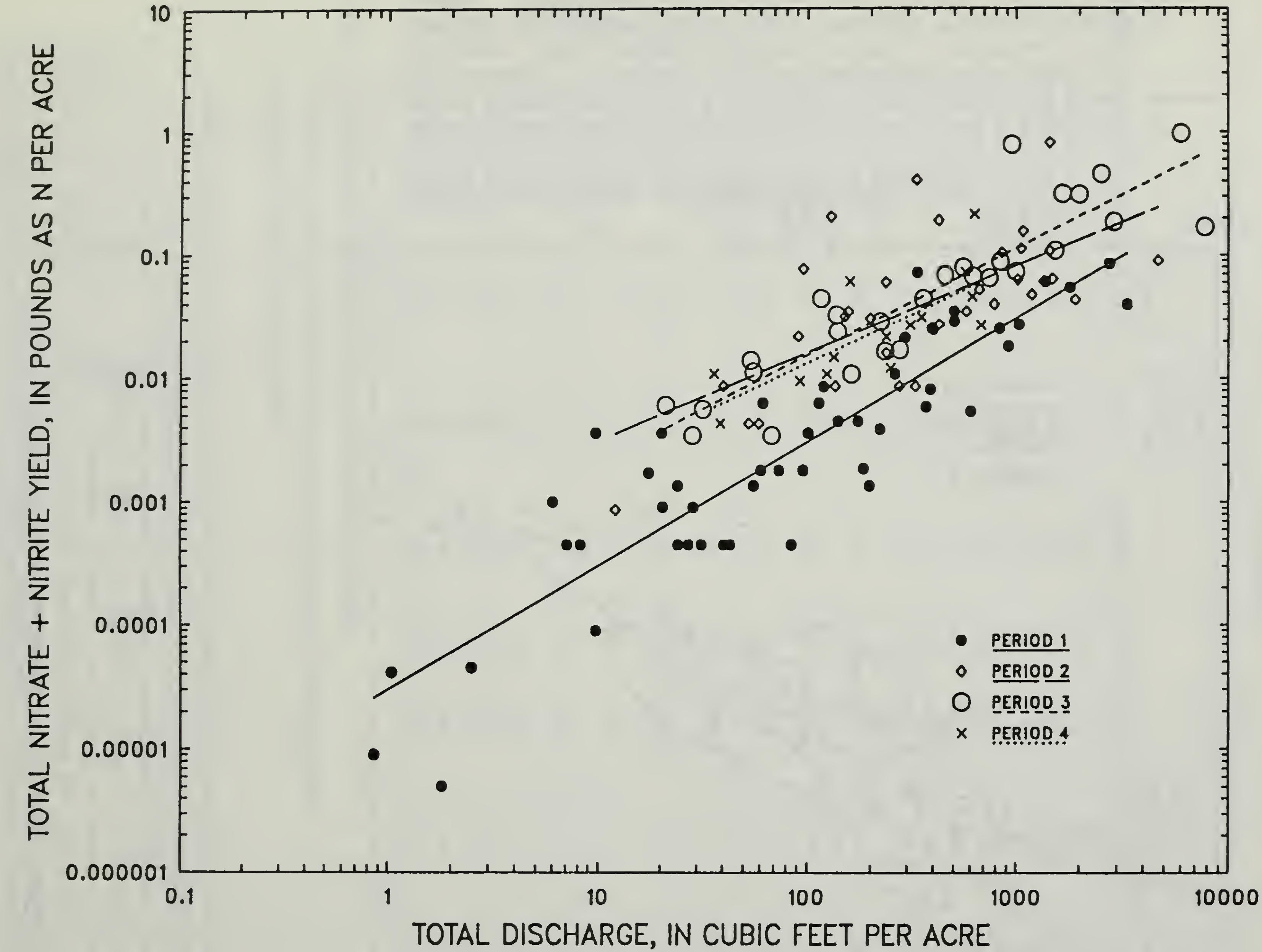


Figure 7.4-18.-- Total nitrate plus nitrite yield in runoff as a function of total discharge for all storms except storms on frozen ground for Periods 1 (January 1983 through September 1984), 2 (October 1984 through September 1986), 3 (October 1986 through September 1988), and 4 (October 1988 through July 1989). (Regression statistics are listed in Table 7.4-13).

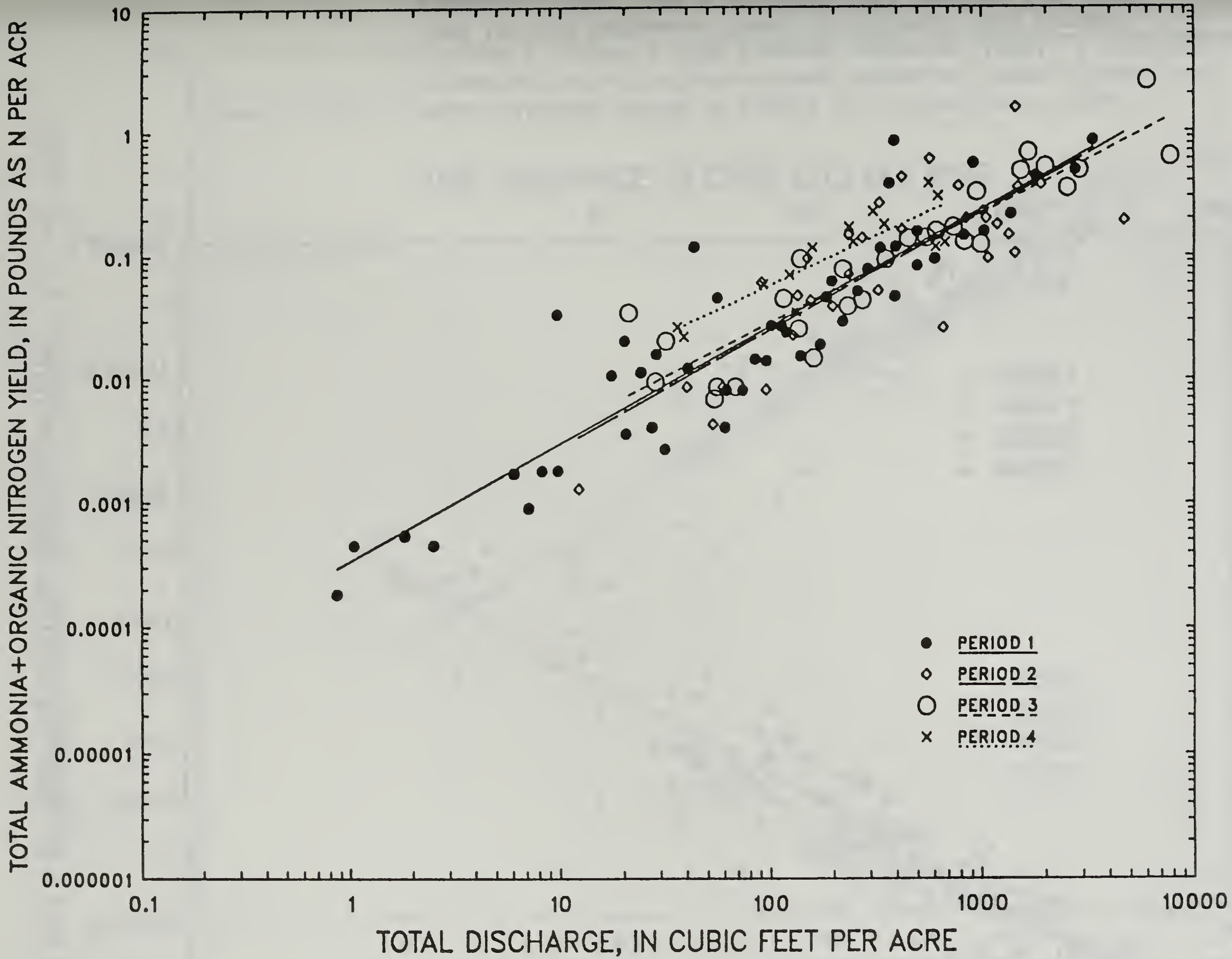


Figure 7.4-19.-- Total ammonia plus organic nitrogen yield in runoff as a function of total discharge for all storms except storms on frozen ground for Periods 1 (January 1983 through September 1984), 2 (October 1984 through September 1986), 3 (October 1986 through September 1988), and 4 (October 1988 through July 1989). (Regression statistics are listed in Table 7.4-13).

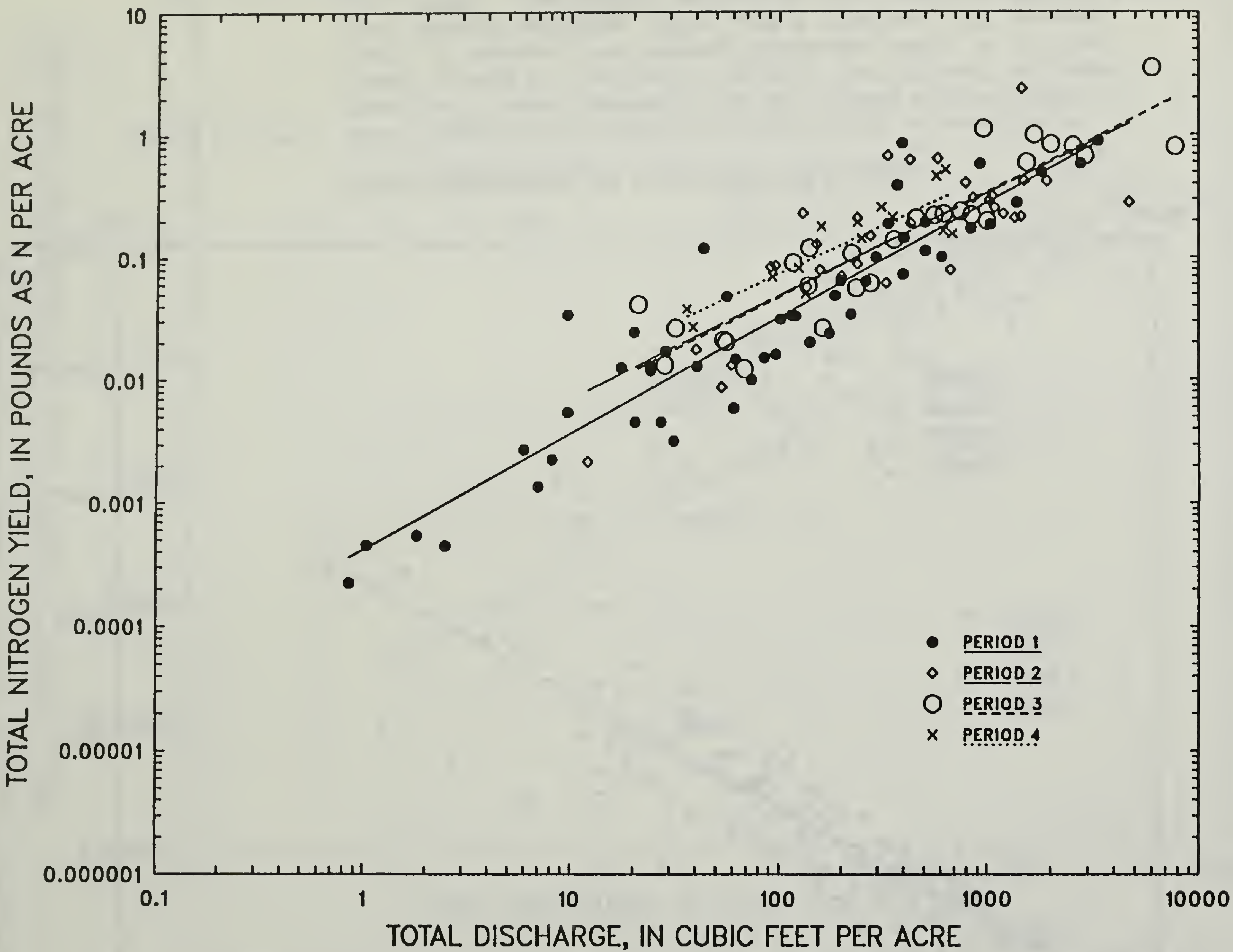


Figure 7.4-20.-- Total nitrogen yield in runoff as a function of total discharge for all storms except storms on frozen ground for Periods 1 (January 1983 through September 1984), 2 (October 1984 through September 1986), 3 (October 1986 through September 1988), and 4 (October 1988 through July 1989). (Regression statistics are listed in Table 7.4-13).

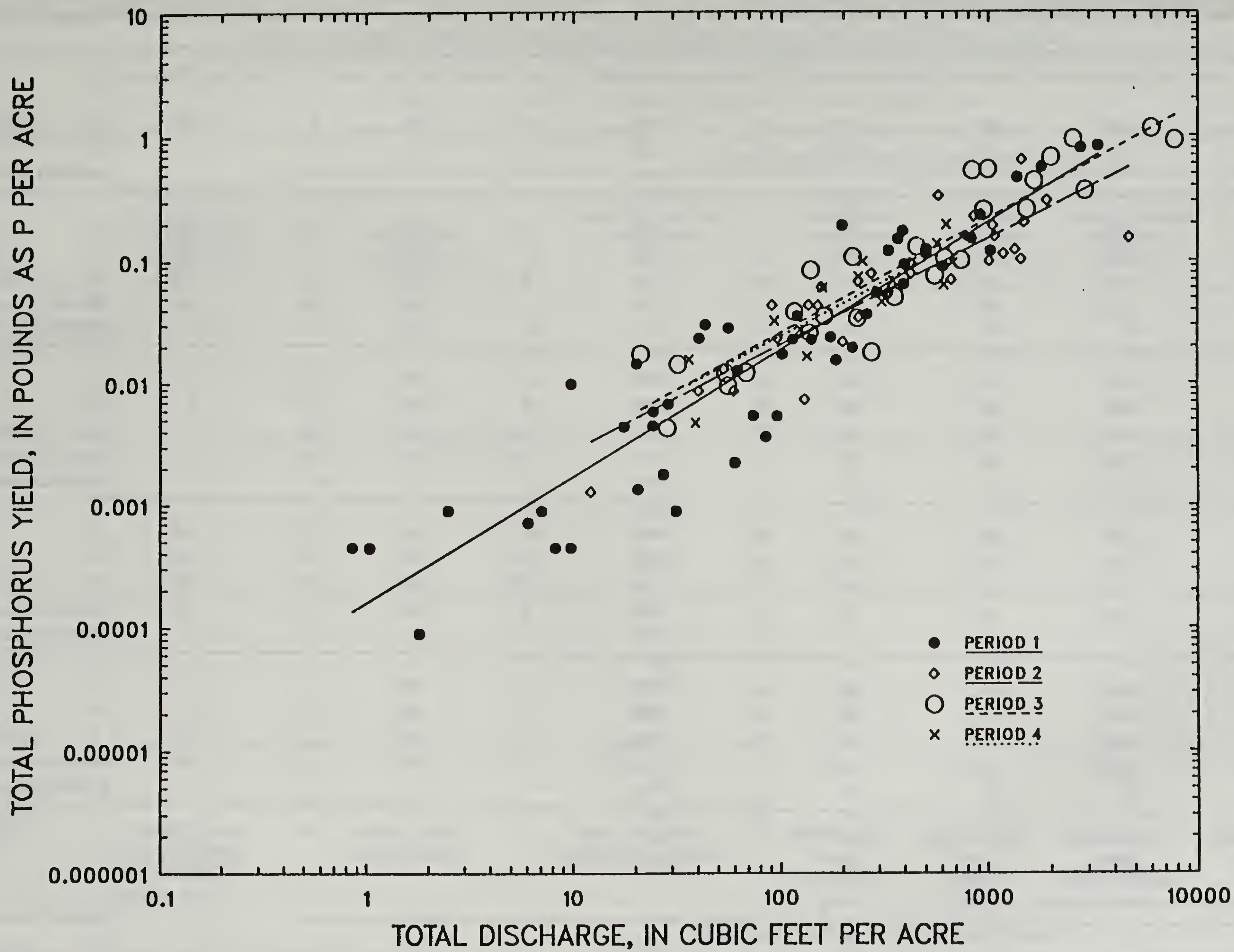


Figure 7.4-21.-- Total phosphorus yield in runoff as a function of total discharge for all storms except storms on frozen ground for Periods 1 (January 1983 through September 1984), 2 (October 1984 through September 1986), 3 (October 1986 through September 1988), and 4 (October 1988 through July 1989). (Regression statistics are listed in Table 7.4-13).

Table 7.4-13.--Summary statistics for all storms (except storms on frozen ground) and storms producing runoff (except storms on frozen ground) from Field-Site 1 of mean storm and total discharges and nutrient mean storm concentrations and total storm yields for Period 1 (1983-84), the entire post-BMP period (1985-89), Period 2 (1985-86), and Period 3 (1987-88) within clusters (table 7.4-9 and fig. 7.4-15)

[n, number of storms; ft^3/s, cubic foot per second; mg/L, milligrams per liter; ft^3/acre, cubic foot per acre; lb/acre, pound per acre; --, data not comparable; *, insufficient data points for comparison]

Period	Median value for all storms[1]		Median value for storms which produced runoff								
	n	Total discharge yield (ft^3/acre)	n	Total discharge yield (ft^3/acre)	n	Suspended-sediment yield (tons/acre)	n	Total phosphorus yield (lb/acre as P)	Total nitrogen yield (lb/acre as N)	Total ammonia + organic nitrogen yield (lb/acre as N)	Total nitrate + nitrite yield (lb/acre as N)
Medians for Cluster 1											
1	31	85	21	120	19	0.010	12	0.029	0.041	0.038	0.005
Post-BMP	61	0	21	120	12	.034	12	.059	.12	.094	.030
2	24	0	5	240	4	.068	4	.055	.17	.12	.035
3	21	0	7	240	7	.034	7	.083	.12	.093	.029
Medians for Cluster 6											
1	18	52	13	102	9	.028	8	.12	.18	.13	.016
Post-BMP	34	520	31	580	28	.055	25	.10	.22	.16	.063
2	20	450	18	520	17	.074	15	.098	.25	.18	.061
3	10	400	9	740	8	.019	7	.44	.22	.13	.073
Medians for Cluster 7											
1	67	0	26	24	22	.006	17	.005	.010	.008	.001
Post-BMP	161	0	27	110	15	.005	10	.030	.057	.030	.009
2	63	0	16	110	8	.004	6	.043	.071	.050	.009
3	73	0	10	80	6	.005	3	.026	.041	.026	.011
Medians for Cluster 8											
1	15	205	13	260	7	.035	6	.11	.063	.057	.006
Post-BMP	28	294	26	330	24	.009	18	.065	.19	.12	.045
2	7	1,050	7	1,050	7	.011	5	.069	.23	.043	.052
3	12	260	12	260	10	.003	7	.038	.089	.045	.044
Medians for Cluster 3											
1	22	0	8	47	7	.001	5	.010	.014	.011	.000
Post-BMP	14	19	9	82	5	.004	3	.016	.050	.035	.015
2	2	0	*	*	*	*	*	*	*	*	*
3	0	60	*	*	*	*	*	*	*	*	*

[1]Total and mean discharge set equal to zero if no runoff.

Table 7.4-13.--Summary statistics for all storms (except storms on frozen ground) and storms producing runoff (except storms on frozen ground) from Field-Site 1 of mean storm and total discharges and nutrient mean storm concentrations and total storm yields for Period 1 (1983-84), the entire post-BMP period (1985-89), Period 2 (1985-86), and Period 3 (1987-88) within clusters (table 7.4-9 and fig. 7.4-15)--Continued

[n, number of storms; ft^3/s, cubic foot per second; mg/L, milligrams per liter; $ft^3/acre$, cubic foot per acre; lb/acre, pound per acre; --, data not comparable; *, insufficient data points for comparison]

	Median value for all storms[1]		Median value for storms which produced runoff								
Period	n	Mean storm discharge (ft^3/s)	n	Mean storm discharge (ft^3/s)	n	Mean suspended-sediment concentration (mg/L)	n	Mean total phosphorus concentration (mg/L as P)	Mean total nitrogen concentration (mg/L as N)	Mean ammonia + organic nitrogen concentration (mg/L as N)	Mean nitrate + nitrite concentration (mg/L as N)
Medians for Cluster 1											
1	31	0.10	21	0.29	19	2,870	12	2.6	3.4	2.7	0.56
Post-BMP	--	--	--	--	12	3,300	12	3.0	6.8	5.3	1.5
2	--	--	--	--	4	7,489	4	3.8	11	8.7	2.2
3	--	--	--	--	7	2,030	7	2.7	6.1	4.2	1.7
Medians for Cluster 6											
1	18	.12	13	.38	9	9,040	8	4.1	5.4	4.6	.54
Post-BMP	--	--	--	--	28	3,520	25	2.9	5.8	3.8	1.6
2	--	--	--	--	17	4,870	15	2.5	5.4	3.6	1.4
3	--	--	--	--	8	1,850	7	3.4	6.2	4.2	1.8
Medians for Cluster 7											
1	67	.00	26	.04	22	3,530	17	3.1	5.2	4.1	.59
Post-BMP	--	--	--	--	15	930	10	3.6	8.0	4.4	1.5
2	--	--	--	--	8	1,070	6	4.1	7.6	4.1	1.0
3	--	--	--	--	6	725	3	3.4	7.4	3.2	4.1
Medians for Cluster 8											
1	15	.10	13	.10	7	1,930	6	3.1	4.1	3.6	.43
Post-BMP	--	--	--	--	24	501	18	3.0	8.4	4.5	2.3
2	--	--	--	--	7	300	5	2.6	4.8	3.1	1.8
3	--	--	--	--	10	470	7	4.3	7.2	4.8	3.0
Medians for Cluster 3											
1	22	.00	8	.10	7	1,690	5	3.2	3.6	2.5	.24
Post-BMP	14	--	--	--	5	1,620	3	3.2	8.3	7.4	1.8
2	2	--	--	--	*	*	*	*	*	*	*
3	2	--	--	--	*	*	*	*	*	*	*

for Period 1 than Period 3. The distribution of the data may bias the statistical analysis within cluster 1 because no runoff was produced with similar type storms during the post-BMP periods.

Within each cluster and for all comparisons but one, the mean storm nitrate + nitrite concentrations and total storm nitrate + nitrite yields increased significantly (changes were from 2 to 9-fold), from the pre-BMP to post-BMP periods (table 7.4-10 and 7.4-13). Therefore, regardless of the type of storm, more nitrate was available to runoff. During storms when no runoff was produced, after terrace construction, overall soil moistures may have increased, allowing for increased nitrification, and therefore increased amounts of nitrate that were available to all the storms producing runoff. During all storms after terracing, the soil wetting area probably increased from increase sheet runoff and a reduction in gully runoff. Thus, the increased contact time and the possibly increased contact area of the runoff water with the nutrient-rich soils allowed for an increase in the conversion to and dissolution of nitrate. During many storms, runoff pooled in the terraces, which also allowed for increased nitrification and increased solution of nitrate.

Table 7.4-13 shows that the median total nitrogen storm concentrations in runoff from Period 1 were always less than or equal to the total nitrogen concentrations for each of the other periods. However, a significant increase in mean storm total-nitrogen concentrations was only detected from Period 1 to Period 3 for storms in Clusters 1 and 8. The distribution of data within Cluster 1 may bias this statistical analysis as discussed previously. The increase in total nitrogen for Cluster 8 storms was primarily because of the large increases in nitrate concentrations. A significant increase in mean ammonia + organic nitrogen was also detected for Cluster 1, Period 1 versus post-BMP period and Period 1 versus Period 2.

A decrease in mean storm total-phosphorus concentrations was detected (90 percent confidence interval) for storms in Cluster 6 from Period 1 to Period 2 but no change was detected between Period 1 and Period 3. Because phosphorus sorbs tightly to soil particles, the change in phosphorus concentrations may have resulted from a change in suspended sediment transported by these storms. Storms in Cluster 6 produced the largest suspended-sediment concentrations during Period 1 (table 7.4-13) and the largest decreases in suspended-sediment concentrations were noted between Period 1 and Periods 2 and Period 1 and Period 3 (median concentrations decreased by 4,200 and 7,200 mg/L, respectively).

Total phosphorus concentrations did not decrease proportionately with suspended-sediment concentrations throughout most of the storm groupings (table 7.4-13). It is believed, from observation and limited particle-size data analysis that most of the fine sediment particles (less than 0.62 micrometers in diameter) continued to be discharged from the site after terracing, and that most of the phosphorus was transported with these particles. Particle-size analysis showed that a significantly larger percentage of the sediment in runoff was silt and clay (sediment finer than 0.62 micrometers in diameter) after terracing (a median of 96 percent, data from 1986, 1987, and 1988 water years) than before terracing (a median of 86 percent) (fig. 7.4-22). Limited phosphorus concentration data show that a median of 90 percent of the total phosphorus in runoff was suspended before terracing, and 82 percent after terracing (fig. 7.4-23). Using the Mann-Whitney test, the total and suspended phosphorus concentration did not change significantly from the pre-BMP to post-BMP periods, but the dissolved phosphorus increased significantly. The small number of samples weaken any conclusions from the data analysis, but it is possible that small dissolved phosphorus increases offset any suspended-phosphorus decrease that may have occurred.

During the analysis of pre-BMP data, an attempt to relate the principal agricultural activity and precipitation factors to nutrients in runoff was made using graphical and multiple regression analysis. Runoff events that occurred when the ground was frozen and immediately following plowing were excluded from the analysis. Graphical and regression analyses indicated that a general increase in mean total-nitrogen concentrations occurred with increasing nitrogen applications in the 15, 30, or 45 days before the runoff event (30 days produced the best correlations) (fig. 7.4-24a and table 7.4-14) (P.L.Lietman and others, U.S. Geological Survey, written commun., 1990). Four runoff events, which occurred during late July through September 1984 when no nutrient applications had been made to the field for 45-113 days because of the crop cover, were excluded from the data set because they occurred under different conditions than the other events. Precipitation factors considered in the data analyses included total inches of precipitation, hours of precipitation duration, antecedent soil-moisture conditions, and precipitation intensity. Only the addition of precipitation was statistically significant in the regression (table 7.4-14) and the analysis

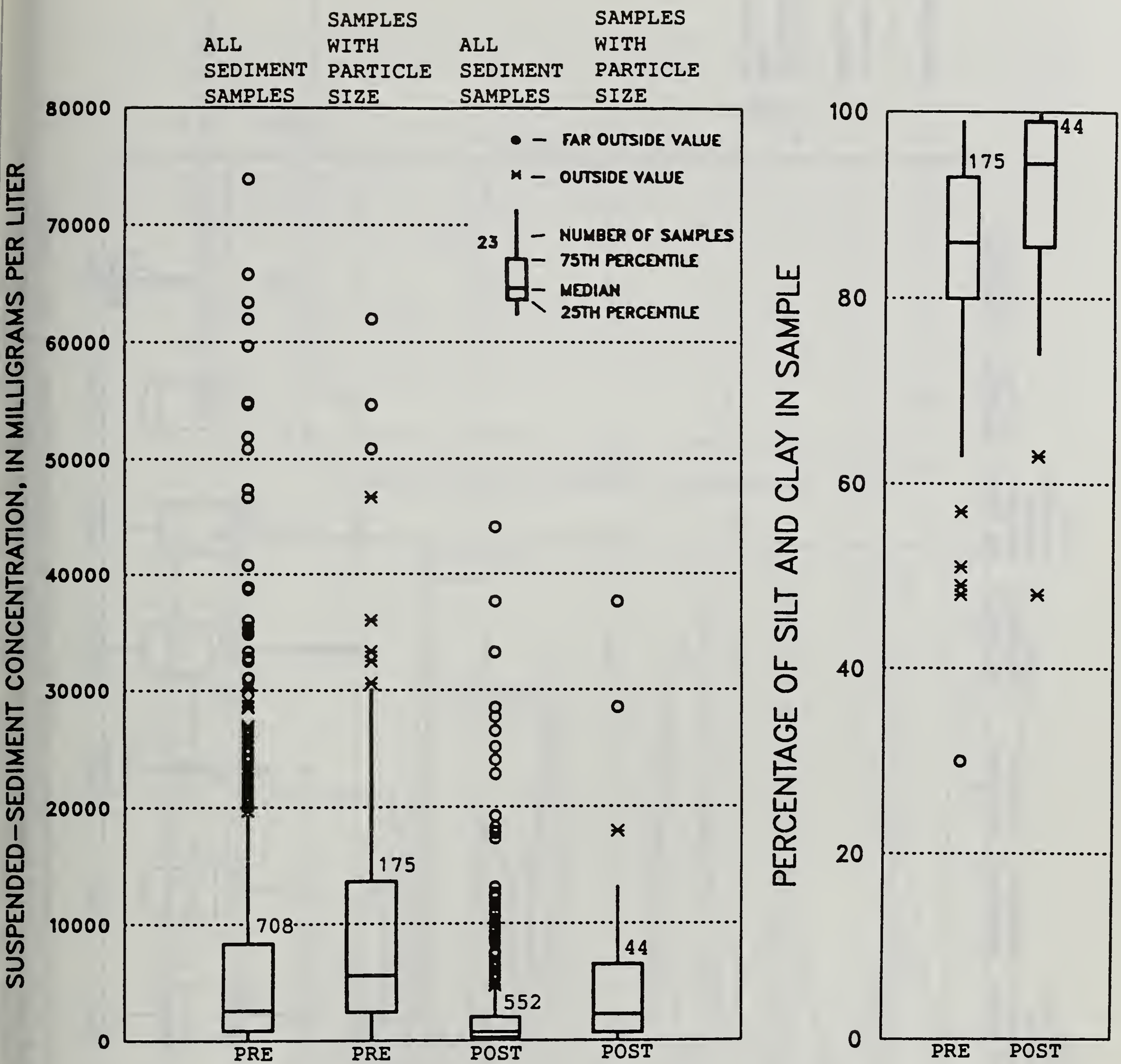


Figure 7.4-22.-- Suspended-sediment concentrations in all samples and in samples analyzed for particle size (left), and percentage of silt and clay in samples analyzed for particle size (right) during the pre-BMP (January 1983 through September 1984) and part of the post-BMP period (October 1985 through September 1988) at Field-Site 1.

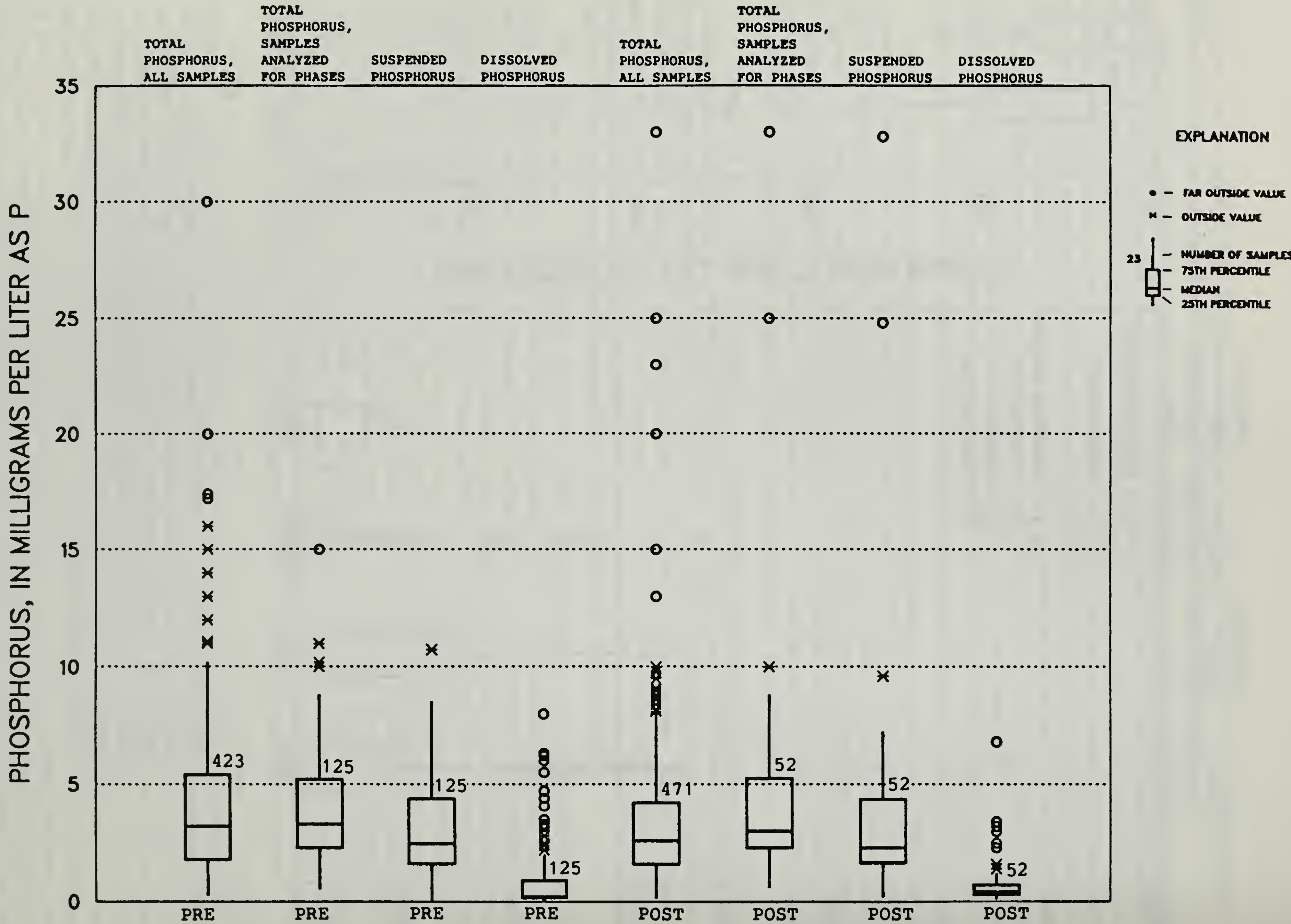


Figure 7.4-23.-- Distribution of instantaneous total phosphorus concentrations in all runoff samples and phase of phosphorus in a limited number of samples during the pre-BMP (January 1983 through September 1984) and part of the post-BMP period (October 1985 through September 1988) at Field-Site 1.

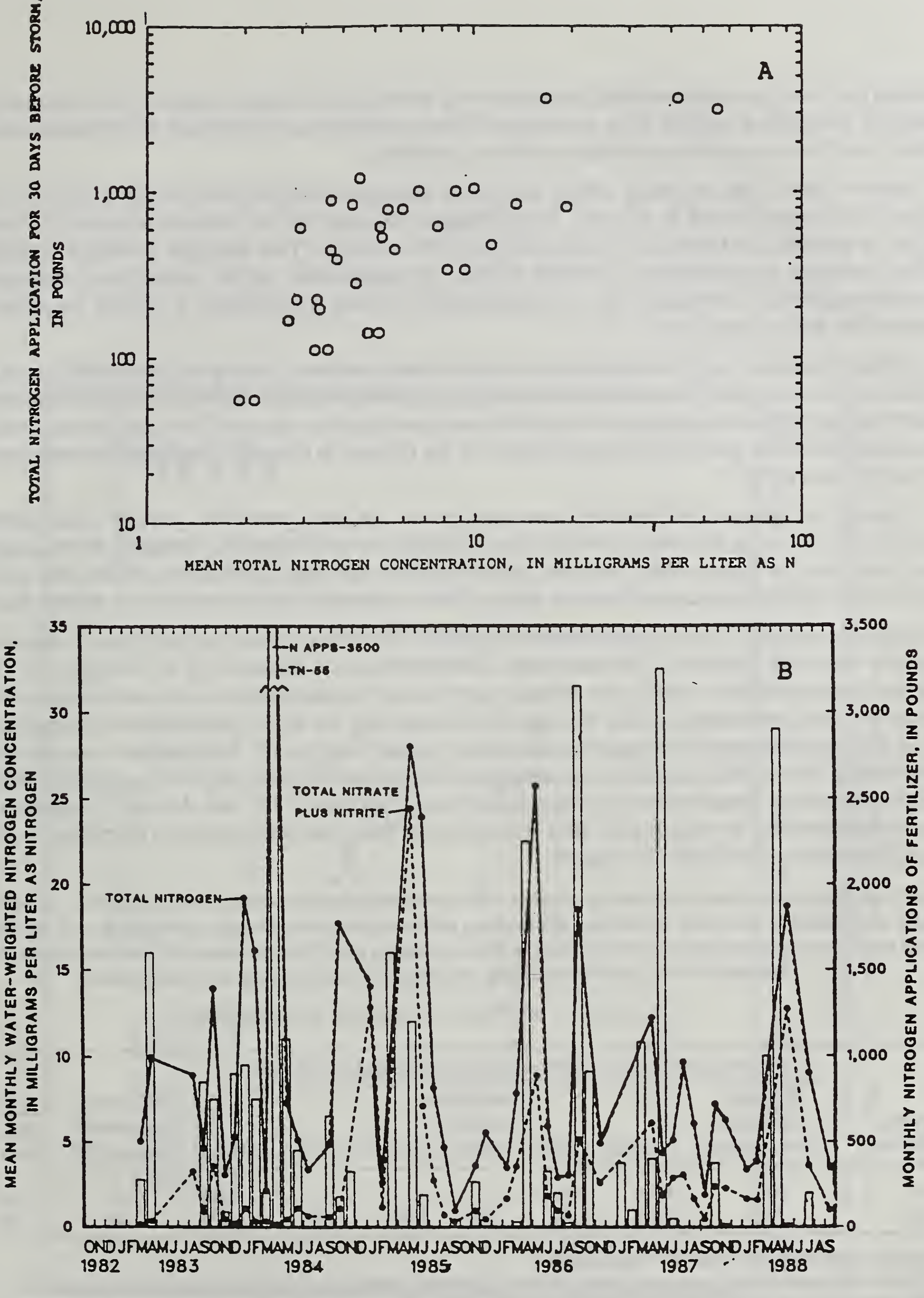


Figure 7.4-24.-- Relation of total nitrogen applications made to Field-Site 1 for 30 days prior to a runoff event to mean total nitrogen concentration for runoff events on table 7.4-14, January 1983 through September 1984 (A) and mean monthly total nitrogen and nitrate concentrations in runoff from sampled storms and monthly nitrogen applications of manure and commercial fertilizer to Field-Site 1, January 1983 through September 1988 (B).

indicates that nitrogen concentration decreases with increasing duration, implying that concentrations are diluted by continuing rainfall. This same type of data analysis was performed with phosphorus data but did not result in any significant relations between variables.

Another factor that probably affects the mean nitrogen concentration during a runoff event is the amount of nitrogen bound to the soil. Total nitrogen accounts for an average of about 0.25 percent (by weight) of the soil, on the basis of soil analysis of the top 2 in. This nitrogen probably contributes to a baseline nitrogen concentration in runoff which, by examination of the runoff data, appears to have occurred regardless of fertilizer use. A quantification of this contribution to runoff, however, was not possible with the existing data.

Although nutrient applications were not substantially reduced during the post-BMP period, nutrient applications were generally made a little less frequently. Because many storms during the post-BMP period occurred when no field applications of nutrients had been made in the past 30 days, the same data analysis is not possible for the post-BMP period. However, the change in timing of applications may have affected the nutrients in runoff.

Although a quantitative analysis was not made for the post-BMP period, data presented on figure 7.4-24b, showing the mean monthly total nitrogen concentration for sampled storms, indicate that mean storm total nitrogen concentrations generally reflect nitrogen applications to the site. Additionally, figure 7.4-24b shows the increase in mean storm nitrate concentrations in runoff after terrace construction.

Although atrazine was the predominant herbicide detected in runoff at Field-Site 1, metolachlor and cyanazine were also detected. The maximum concentrations of atrazine, up to 140 μg/L, in runoff was measured during the first storms after atrazine applications. Concentrations of atrazine in runoff decreased from the peak concentrations in May through the summer (fig. 7.4-25). Concentrations of atrazine in the top 2 in. of soil declined rapidly during the same time period (fig. 7.4-11). Metolachlor was also detected in runoff during 1984-86 and cyanazine was detected in runoff in 1987 after they were applied to the site. Each year, the maximum concentrations of metolachlor and cyanazine (137 and 46 mg/L, respectively) were found during the first storm sampled after application in May, and concentrations decreased in subsequent storms to near detection limits by August.

Table 7.4-14.--Regression statistics for the log of mean event total-nitrogen concentrations in runoff, in milligrams per liter as nitrogen, as a function of the log of nitrogen application and precipitation-duration variables for all runoff events with measured nitrogen concentrations and precipitation data, excluding runoff events where no nutrient applications had been made for 45-113 days previously and runoff events occuring on frozen ground

[lb, pound; <, less than; --, not entered into regression]

	Coefficients and associated statistics for logs of independent variables								Standard error		
Degrees of freedom[1]	Nitrogen application[2] (lb as nitrogen)	t-statistic	p-value	Precipitation duration (hours)	t-statistic	p-value	Intercept	Coefficient of determination (adjusted R^2)[3]	Log units	Percent, plus/minus[4]	
35	.550	6.881	<.001	--	--	--	-.685	.57	.216	64	39
35	.535	7.144	<.001	-.149	2.451	.020	-.578	.62	.202	59	37

[1] Degrees of freedom is number of samples minus 1.
[2] Pounds of nitrogen as manure or commercial fertilizer applied to the field in the 30 days preceding the runoff event.
[3] R^2 adjusted for degrees of freedom to permit comparison of regression models based on different sets of data.
[4] Calculated as described by Tasker (1978).

7.4.5 Field-Site 1 Ground-Water Quantity and Quality

The characterization of the hydrogeology of Field-Site 1 was performed early in the study to facilitate design of an effective ground-water monitoring network and to provide a framework for the interpretation of monitoring results (D.W. Hall, U.S. Geological Survey, written commun., 1990). Ground-

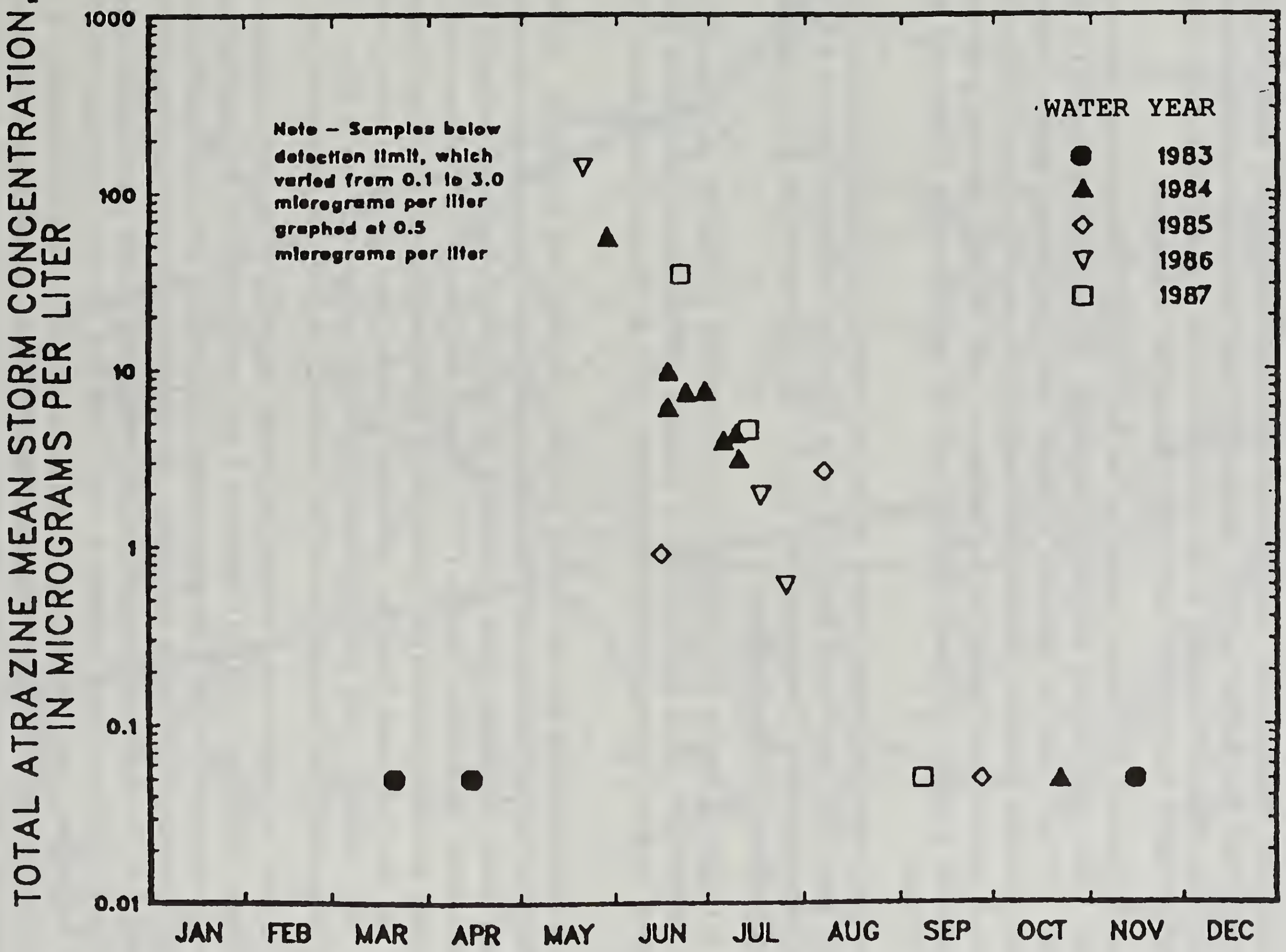


Figure 7.4-25.-- Mean flow-weighted storm concentration of atrazine at Field-Site 1 for the 1983-1987 water years.

water quality analyses were performed throughout the study to define ground-water quality prior to the implementation of agricultural BMPs and to select parameters to define the effects of BMPs on ground-water quality.

The three-dimensional configuration of the ground-water-flow system at Field-Site 1 was determined by geologic interpretation of outcrops and well logs. Water-level data from fourteen monitoring wells were used to determine the water-table configuration and flow direction. Based on the monitoring results, the ground-water basin at the site was determined to be slightly larger than the surface-water basin. Boundaries for the ground-water basin were estimated from recorded water levels, geology, and topographic features. Discharge from the ground-water-flow system occurred along the eastern boundary at the Conestoga River and its unnamed tributary. Northern, western, and southern boundaries of the ground-water-flow system existed at ground-water divides nearly coinciding with surface-water divides (fig. 7.4-26). Coincident surface-water and ground-water divides on the northwest and southern boundaries were assumed reasonable based on topographic relief and observed water levels (figs. 7.4-26, 7.4-27, and 7.4-28). The western boundary of the ground-water-flow system was more difficult to locate because topographic relief is low and the water table is nearly flat in that area.

A generalized north-south hydrologic section of the land surface and the water table (fig. 7.4-27) was constructed using USGS topographic maps and measured water levels in wells LN 1660, LN 1650, LN 1651, LN 1659, LN 1648, and the farmer's domestic well. Monitoring results indicated the steep hydraulic gradient from the northern boundary of the site in the vicinity of wells LN 1649 and LN 1660 extended down to a ground-water trough in the vicinity of well LN 1650. Moving southward from well LN 1650, the hydraulic gradient increased slightly until the ground-water divide was reached in the vicinity of well LN 1648.

A generalized east-west hydrologic section of the land surface and water table also was constructed using topographic maps and water-level data from wells LN 1653, LN 1652, LN 1650, LN 1651, LN 1643, and the unnamed tributary to the Conestoga River (fig. 7.4-28). The water table along this section reflected a subdued approximation of the land surface.

The aquifer in the study area is the Zooks Corner Formation, a dolomitic-rock aquifer under water-table conditions. Water-level data showed that a diabase dike in the north-central part of the site (fig. 7.4-26) impeded the flow of ground water and contributed to an elevated water table in this part of the site.

Unsaturated zone materials at the site are 5 to 70 ft thick and are very permeable. Secondary porosity due to root channels, worm holes, structural deformation, and subsurface erosion in the soils and regolith of the unsaturated zone, facilitated rapid movement of water and dissolved materials from the land surface to the water table (Shuford and others, 1977). A small sinkhole developed near well LN 1646 from 1983 to 1984, possibly providing a direct path for recharge water and surface materials to travel directly to the water table. In the carbonate bedrock, solutionally developed passages along bedding planes, fractures, joints, and cleavage were the dominant pathways for ground-water flow. Lithologic logs indicated that in some areas these passages were filled with silt, clay, or rock fragments (fig. 7.4-29).

The specific yield of an aquifer is the volume of water it will yield by gravity drainage divided by its total volume (Lohman and others, 1972). At Field-Site 1, the specific yield of the saturated ground-water-flow system was estimated from water-level rises measured in well LN 1643 during recharge events under conditions of high antecedent soil-water saturation and negligible evapotranspiration (as described by Gerhart, 1986)(table 7.4-15). Monitoring data from fifteen recharge events were used to calculate specific yields. Nine of these events were from January to April 1983 and six from December 1983 through April 1984, when most vegetation was dormant and soil moisture was at or near field capacity. It was assumed that under these conditions all precipitation became either runoff or ground-water recharge. Precipitation, runoff, and water-level rise, measured for each recharge event, were used to calculate specific yield (tables 7.4-15 and 7.4-16) according to equation (2) discussed in Section 6.9.7.3.

The median estimated specific yield at well LN 1643 was 0.13. Estimates of median specific yield at seven other wells at the site ranged from 0.08 at six wells to 0.14 at well LN 1646 (table 7.4-16). The specific yields at the site were somewhat elevated relative to those in other hydrogeologic settings in Pennsylvania

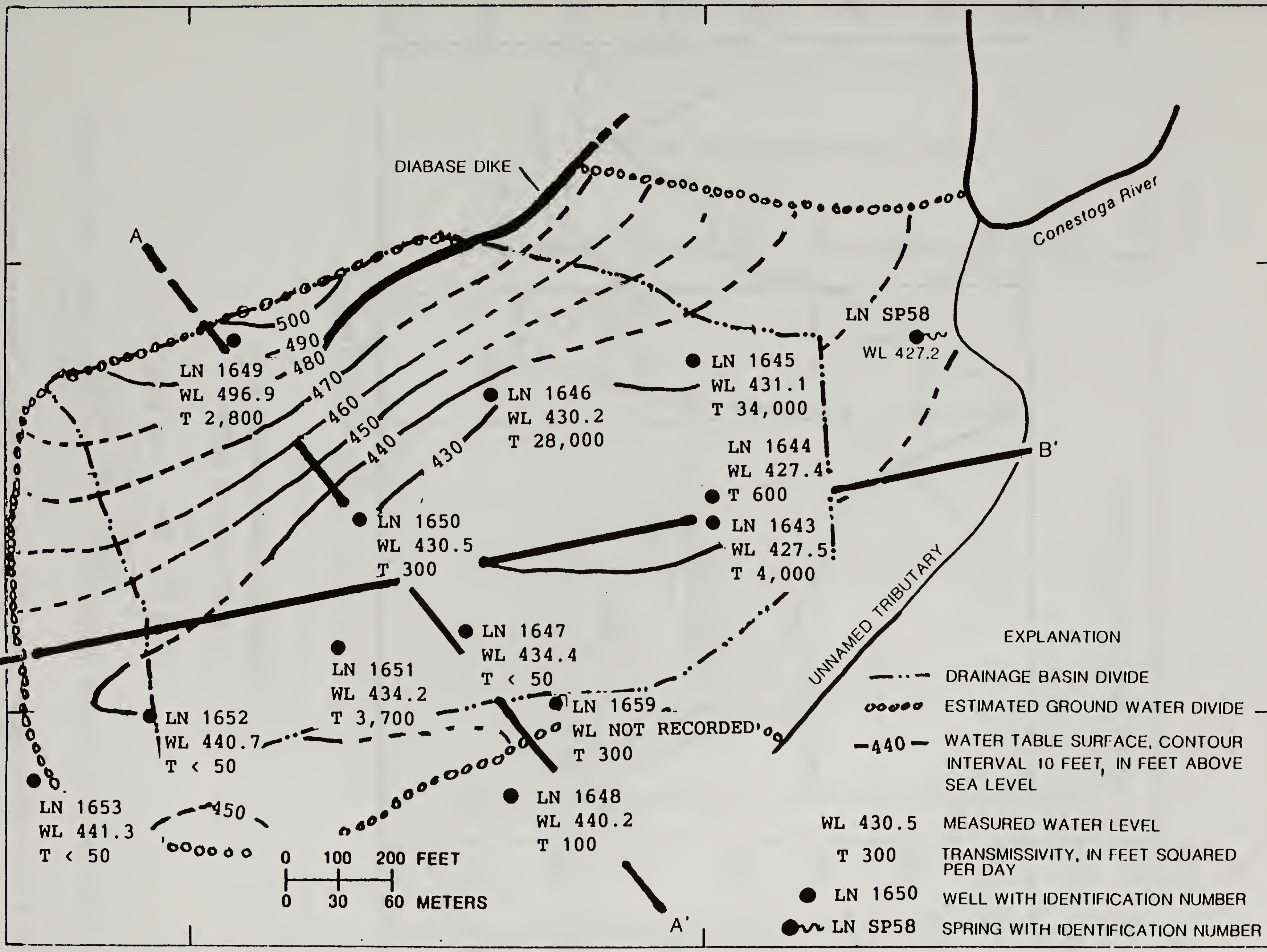


Figure 7.4-26.--Estimated water-table configuration on November 2, 1982, transmissivity of the Zooks Corner Formation, and strikes of geologic cross sections A - A' (figure 7.4-27) and B - B' (figure 7.4-28).

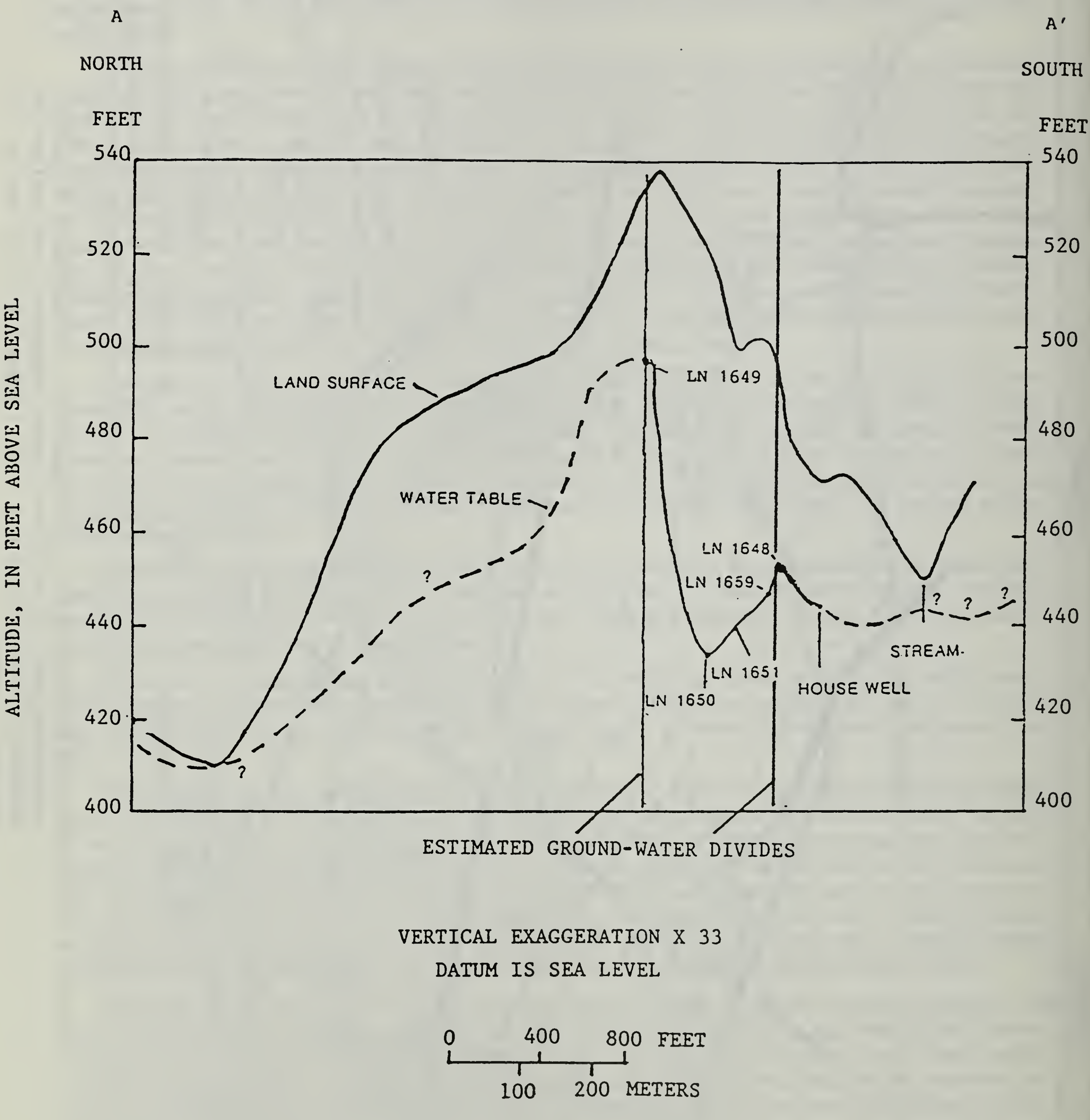


Figure 7.4-27.--Approximate north to south hydrologic section and water-table surface, April 1984.

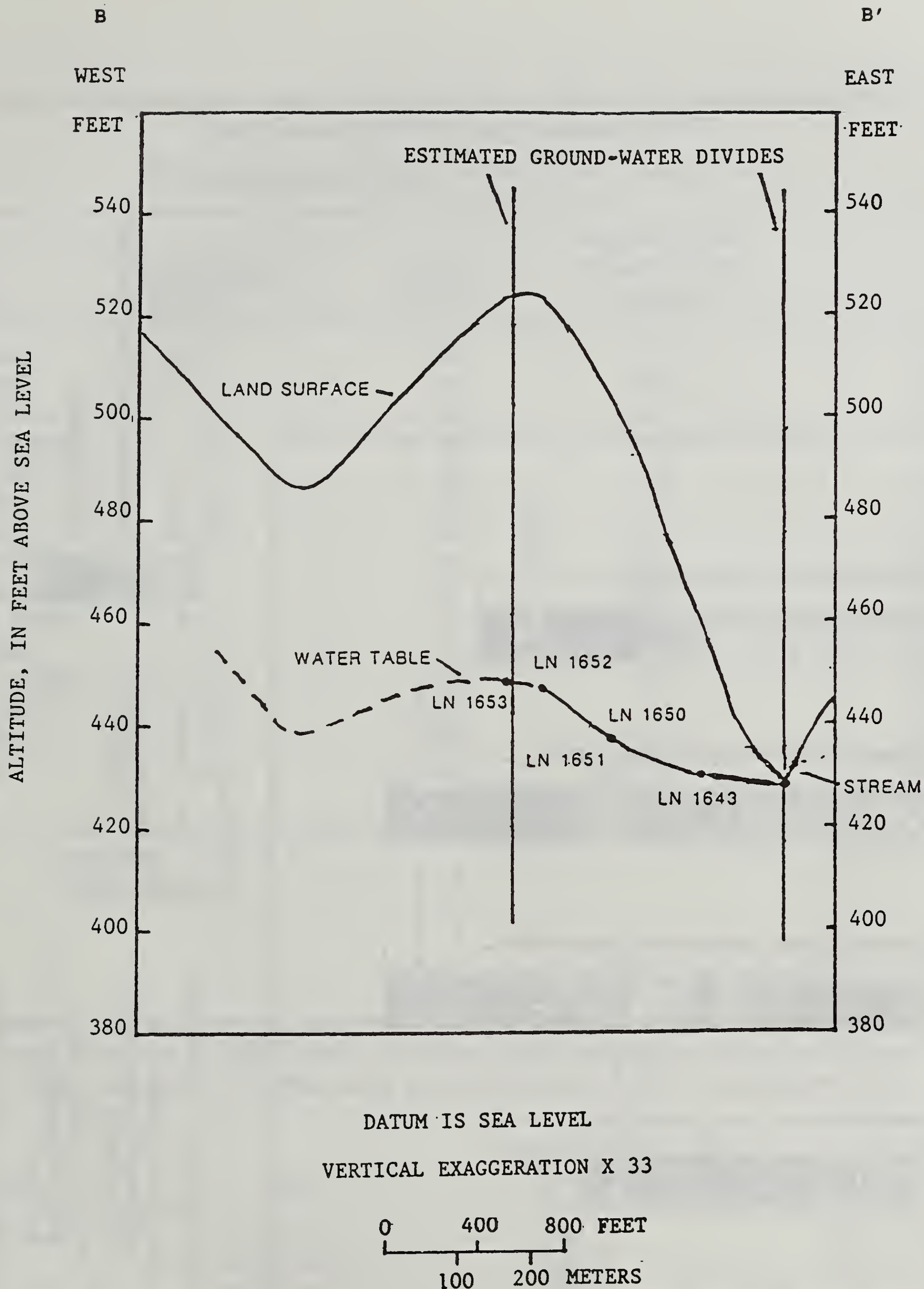


Figure 7.4-28.--Approximate east to west hydrologic section and water-table surface, April 1984.

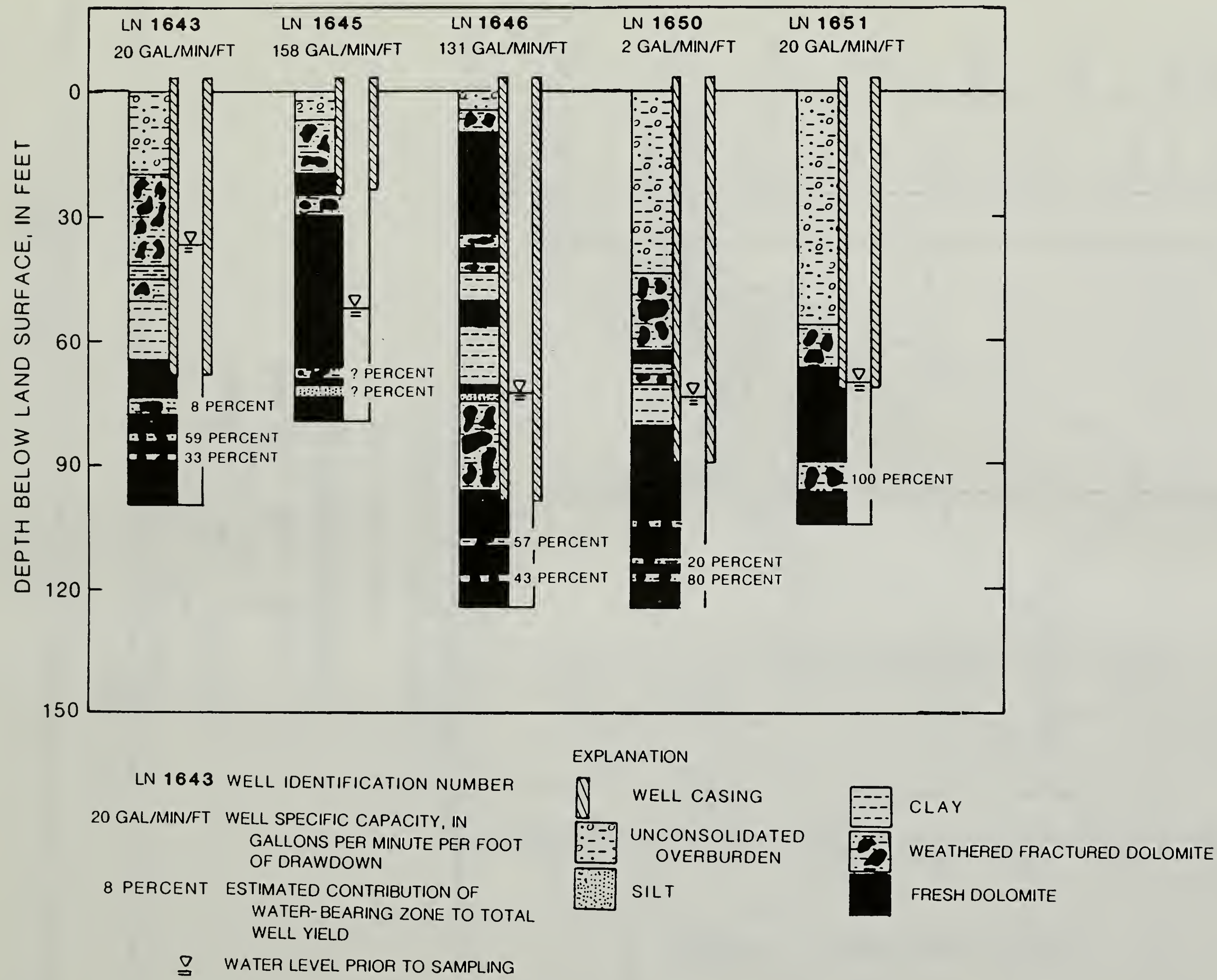


Figure 7.4-29.--Lithology, mean water level, and water bearing zones of wells measured continuously for water level and sampled for water quality, (modified from Gerhart, 1986).

Table 7.4-15.--Precipitation, runoff, water-level rise, and calculated specific yield for well LN 1643, January 1983 through September 1984

[Calculations are based on methods of Gerhart, 1986]

Date	Precipitation (inches)	Runoff (inches)	Water-level rise in well LN 1643 (inches)	Specific yield
Jan. 23, 1983	1.5	0.10	7.7	0.18
Feb. 2-4, 1983	1.1	.04	15.0	.03
March 10, 1983	.35	.01	3.7	.09
March 18-19, 1983	.60	.01	4.3	.13
March 21, 1983	1.0	.07	5.5	.16
April 3, 1983	.60	.01	5.4	.11
April 8, 1983	.50	.02	2.6	.18
April 9-10, 1983	1.3	.19	13.0	.09
April 15-16, 1983	2.6	.26	17.8	.14
Dec. 12-13, 1984	4.6	1.2	38.4	.09
Feb. 15, 1984	1.3	.02	9.1	.13
March 23-24, 1984	1.5	.13	8.0	.17
March 28, 1984	.85	.01	6.4	.13
April 4, 1984	.71	.06	4.8	.14
April 5, 1984	.56	.04	4.5	.12
			AVERAGE SPECIFIC YIELD =	.13

Table 7.4-16.--Water-level rise and calculated specific yields of seven wells for a storm on March 21, 1983, with 1.0 inches of rain and 0.07 inches of runoff, and a storm on April 9-10, 1983, with 1.3 inches of rain and 0.19 inches of runoff

Well	Date	Water-level rise (inches)	Specific yield
LN 1645	03/21/83	7.1	0.13
	04/09-10/83	8.5	.13
LN 1646	03/21/89	6.8	.13
	04/09-10/83	7.9	.14
LN 1647	03/21/83	9.6	.09
	04/09-10/83	13.8	.08
LN 1650	03/21/83	8.4	.11
	04/09-10/83	10.0	.11
LN 1651	03/21/83	8.7	.10
	04/09-10/83	13.8	.08
LN 1652	03/21/83	9.1	.10
	04/09-10/83	11.0	.10
LN 1653	03/21/83	12.1	.08
	04/09-10/83	13.7	.08

(Gerhart, 1984; D.J. Hippe, U.S. Geological Survey, oral commun., 1989) and were attributed to the highly developed secondary porosity. Spatial variation in estimated specific yields were caused by the presence or absence of fractures, joints, faults, voids, and bedding planes that differentially stored or transmitted water (Parizek and others, 1971) in different parts of the site. Temporal variation in the specific-yield estimates probably occurred because of differences in soil moisture between recharge events, and because of the position of the water level in different parts of the aquifer at different times.

The specific capacity of a well is the rate of discharge of water from the well divided by the drawdown of the water level in the well (Lohman and others, 1972). Specific capacities of the wells at the site were calculated on the basis of estimates made by the driller and by aquifer tests at the finished wells. Estimated specific capacities ranged from less than 1 (gal/min)/ft to 160 (gal/min)/ft (median of 9 (gal/min)/ft) (table 7.4-16). The two wells with the greatest specific capacity (LN 1645 and LN 1646) were in the northeastern part of the site. Large variations in the specific capacity of these wells were characteristic of other wells in carbonate aquifers because of the relative presence or absence of fractures, joints, faults, and voids that differentially transmitted water in different parts of the aquifer (Parizek and others, 1971).

Transmissivity is the rate at which water passes through a unit width of aquifer under a unit hydraulic gradient (Lohman and others, 1972). Transmissivity was calculated from estimates of specific capacity using methods described by Driscoll (1986) described in Section 6.9.7.3. The values used for t and Q were from actual aquifer tests, r = 0.25 ft, and S was assumed to be equal to specific yield.

Transmissivity values differed by about three orders of magnitude–from less than 50 ft^2/d at wells LN 1647, LN 1652, and LN 1653, to 34,000 ft^2/d at well LN 1645 (fig. 7.4-26). Large local variations in transmissivity are common in carbonate aquifers with highly irregular dissolution occurring along joints, faults, fractures, and bedding planes (Freeze and Cherry, 1979). Because of a small primary porosity and variable secondary porosity, carbonate aquifers are poorly productive to extremely productive; flow velocities of up to 350 ft per hour have been recorded in the Ordovician limestone near Tussey and Nittany Mountains in central Pennsylvania (Parizek and others, 1971).

At Field-Site 1, areas that are very transmissive have a small hydraulic gradient. The 70-ft relief of the water table between wells LN 1649 and LN 1650 suggests that the transmissivity between wells LN 1649 and LN 1650 is small. In this area, the impermeable diabase dike forces ground water to flow across rather than along bedding. The large clay content of materials in the unsaturated zone in the vicinity of well LN 1649 also probably restricts ground-water flow.

Although the depth of the shallow ground-water-flow system has not been determined, most of the flow probably occurs near the water-table surface (Davis and DeWiest 1966). Ground-water flow in the bedrock at the site is anisotropic and occurs primarily along solution-enhanced joints, fractures, and bedding planes. Most ground water discharges from the site as base flow to the Conestoga River and its unnamed tributary, although a small amount of water discharges from the spring. Because the water table is generally more than 30 ft below the land surface, evapotranspiration from the water table probably does not significantly affect ground-water discharge.

Water-level fluctuations throughout the study period for the five wells equipped with continuous water-level recorders ranged from 3.5 ft at well LN 1645 to 8.6 ft at well LN 1651 (fig. 7.4-30). Temporal variations in water levels measured at these wells were similar throughout the study period. Water levels in each well responded quickly to recharge, and water-level peaks occurred several hours to 1 day following precipitation (figs. 7.4-31 and 7.4-32). Peaked hydrograph response occurred because permeable soils overlie a carbonate aquifer containing solution-enhanced fractures. These conditions permitted rapid movement of water through the site, and in some instances permitted precipitation to reach the water table almost directly. Rapid recharge was probably enhanced by the sinkholes and an intersecting set of vertical joints at the site.

Although Field-Site 1 well hydrographs appear to indicate that more ground-water recharge occurred before the terraces were installed than after, water-level differences were caused by differences in the quantity and timing of precipitation rather than by terrace construction. To illustrate this climatic effect of increased recharge in the periods 1983-84 and 1989, relative to 1985-88, the hydrograph from well LN 514 (fig. 7.4-30), a well located approximately 11 miles away from the site where no land-contouring changes

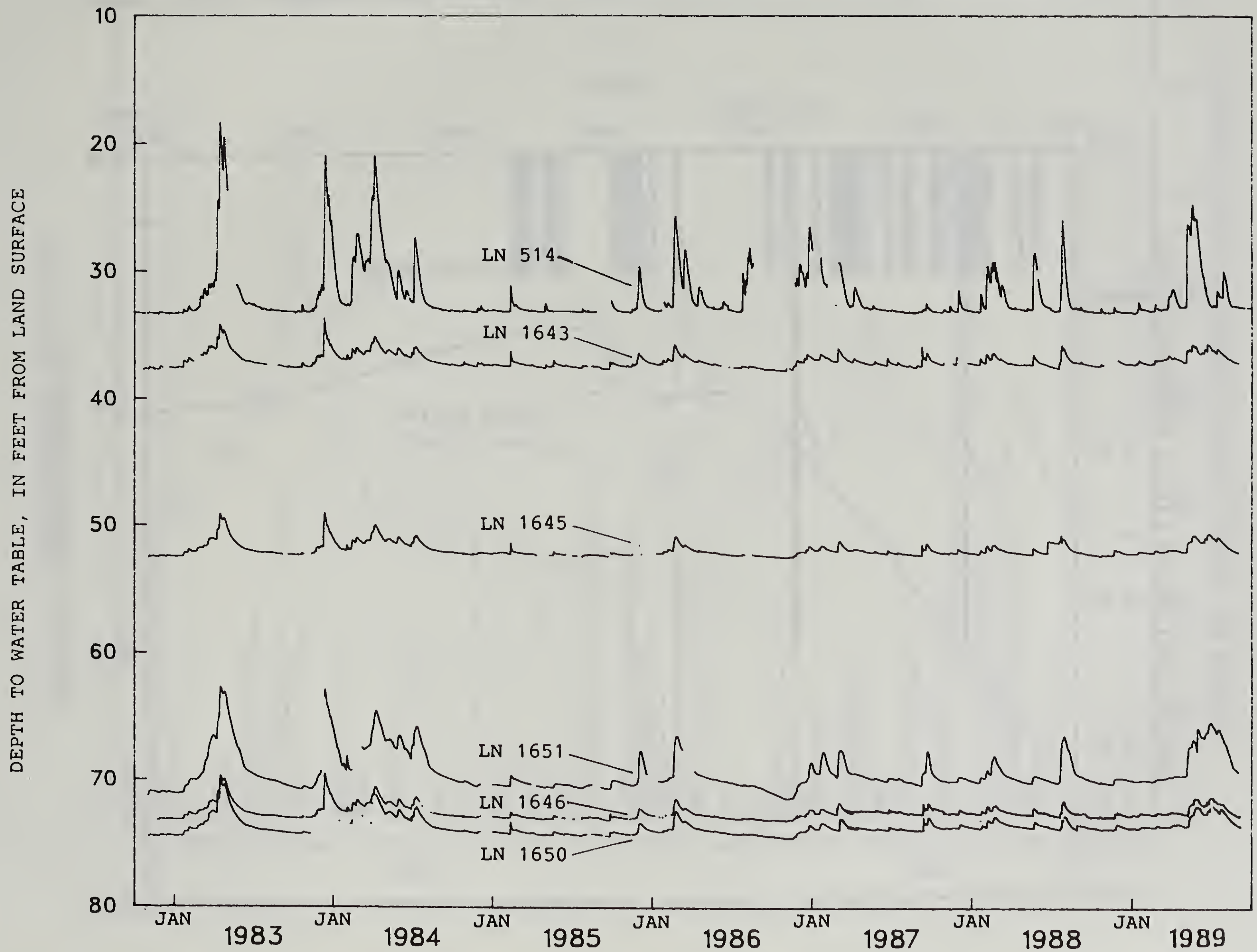


Figure 7.4-30.--Depth to water table from land surface at well LN 514 in Landisville, Pa., and at wells LN 1643, LN 1645, LN 1646, LN 1650, and LN 1651 at Field-Site 1.

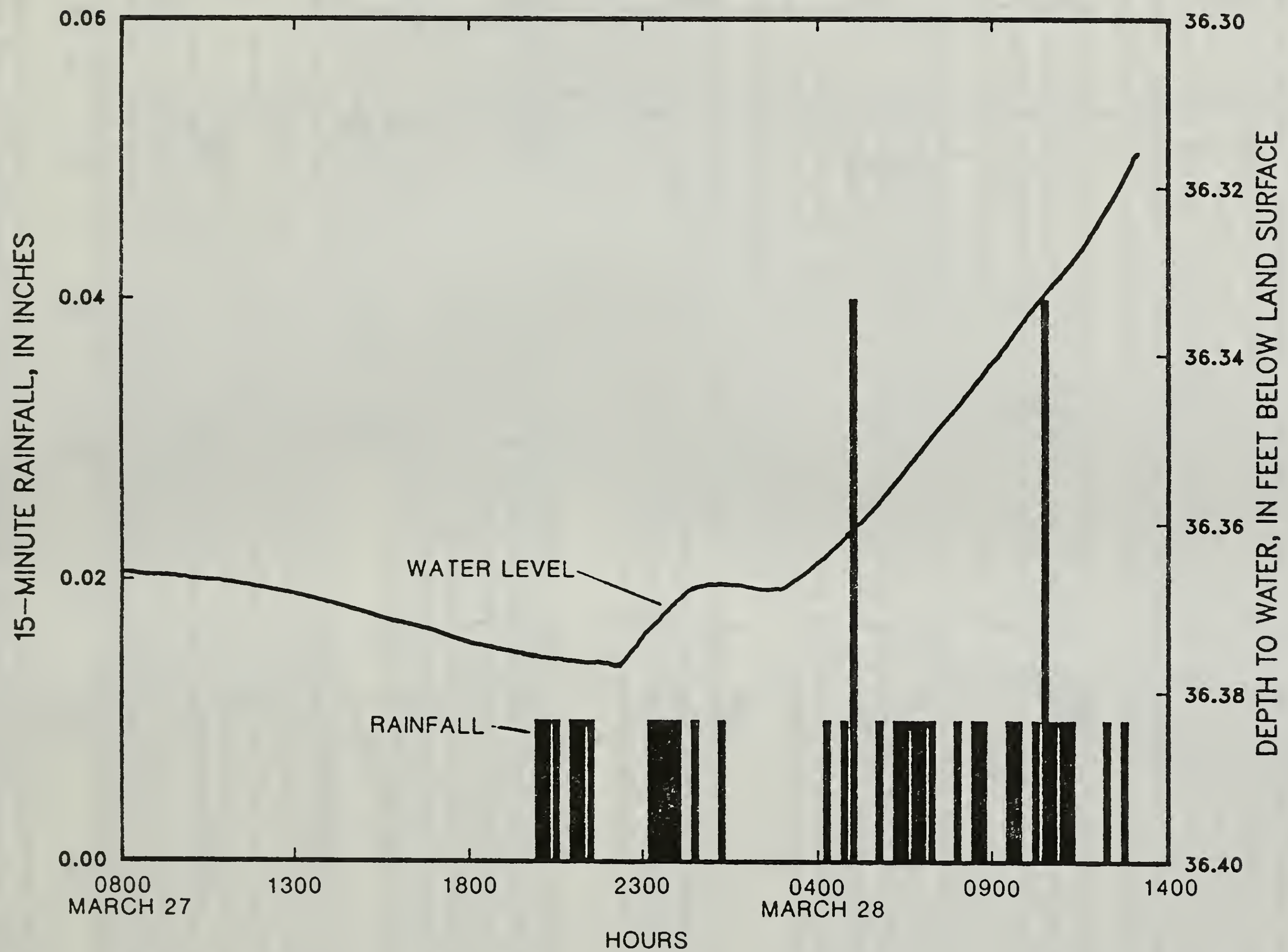


Figure 7.4-31.--Water-level response to precipitation at well LN 1643 for a storm on March 27 and 28, 1984 (modified from Gerhart, 1986).

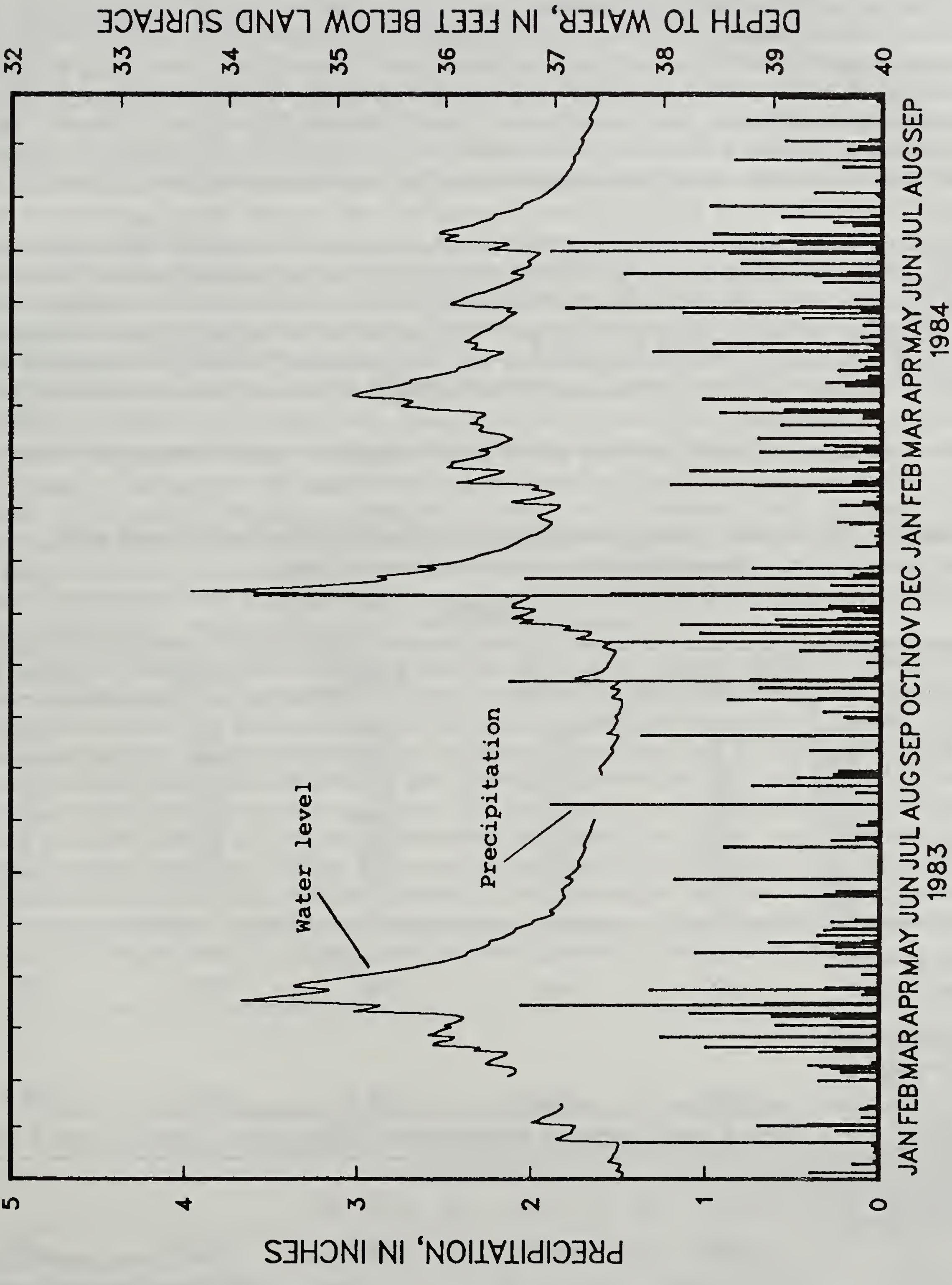


Figure 7.4-32.--Water-level response to precipitation at well LN 1643.

occurred, displays approximately the same proportional shapes during the study period as the Field-Site 1 wells. Most recharge to the ground water at Field-Site 1 occurs in winter or early spring when evapotranspiration rates are low and vegetation is dormant. However, significant recharge can occur in any month depending on the volume, duration, and frequency of precipitation. The construction of terraces at the site during November and December of 1984 did not substantially affect the monthly mean water-table altitudes used to calculate annual mean water-table altitudes shown in table 7.4-17.

Data analysis using double-mass curves indicate that the terraces did not change rates of ground-water recharge at the site. Double-mass curves (Searcy and Hardison, 1960) are based on the fact that cumulatively summed data of a quantity will plot as a straight line against another quantity if changes occurring in the data are proportional, with the slope of the line representing the constant of proportionality. A break in the slope of a double-mass curve can mean that a change in the constant of proportionality between the two quantities occurred at the time of the break. Small breaks in slope that may be obscured by the smoothing of the double-mass curve can be magnified for detailed analysis by using data residuals in the double-mass curve.

Because the numerical values of nonrecharge water-table altitudes (for example, 428 ft above datum) were very large relative to small changes in water-table altitude caused by a recharge event (for example, 1 ft), double-mass plots of data that includes the nonrecharge water-table altitude are insensitive to small changes in water-level altitude caused by recharge. This effect of the nonrecharge water-level altitudes overwhelming the sensitivity of the double-mass curves was eliminated by using data residuals in the double-mass curves. The residuals were obtained by subtracting the minimum water-table altitude for the period of record at a well (table 7.4-17) from the monthly-mean water levels for that well (U.S. Geological Survey Water Data Reports, 1984-90), yielding values that are sensitive to small changes in recharge. For

Table 7.4-17.--Annual mean ground water-level altitude and water-level data from Field-Site 1, in feet above sea level

[--, no data]

		LN 1643	LN 1645	LN 1646	LN 1650	LN 1651
Pre-terracing	1983	428	431	431	431	436
Post-terracing	1984	428	432	431	432	437
	1985	428	431	430	431	435
	1986	428	432	430	431	435
	1987	428	431	430	431	435
	1988	428	431	431	431	435
	1989	--	--	--	--	--
Land-surface elevation, in feet above sea level		465	483	503	505	505
Study period low-water altitude, in feet above sea level		427.1	428.5	428.9	430.4	433.6
Date, low water		Nov. 3, 1986	Nov. 2-5, 1986	Nov. 4, 5, 1986	Nov. 5, 1986	Nov. 6, 1986
Study period high-water altitude, in feet above sea level		431.3	434.0	433.5	434.9	442.4
Date, high water		Dec. 14, 1983	Dec. 15, 1983	Dec. 15, 1983	April 19, 1983	April 19, 1983
Range of water-level fluctuation, in feet		4.2	5.5	4.6	4.5	8.8

example, calculation of the first twelve points of a cumulatively summed residual series for well LN 1643 are shown in table 7.4-18. This process was continued to produce a series of summed residual data (81 points) for the entire period of record (81 months) for each well. Double-mass curves of the summed residual data are shown on figures 7.4-33, 7.4-34, and 7.4-35 along with regression plots of the same data regressed separately as pre-terracing and post-terracing data.

Water-level data were collected at well LN 1659 during 1984 (pre-terracing period) and during 1989 (post-terracing period). Well LN 1659 is located just inside the southern ground-water divide (figure 7.4-26) at the site. However, because well LN 1659 is located outside of the surface-water divide of the site, the water-level record from well LN 1659 was not affected by changes in amounts of recharge caused by the terraces. Therefore, water-level data from well LN 1659 provide a control for comparing the water-level records of wells at the site using the double-mass technique. Although the water-level record from well LN 1659 is incomplete (it is missing data for the year 1983 and the period 1985-88), sufficient record exists to establish that no change in the amount of ground-water recharge occurred upgradient of well LN 1643 (there is no change in the slope of the double-mass curve using data from wells LN 1659 and LN 1643 between 1984 and 1989) (figs. 7.4-33 a and b). Because this residual, double-mass comparison indicates that terracing did not change the amount of recharge entering the aquifer upgradient of well LN 1643, the more complete water-level record from well LN 1643 (complete from January 1983 through September 1989) can also be used as a control to gage the effects of terracing on the amounts of recharge at the other wells. Any break in slope of a double-mass plot that includes data from LN 1643 must be caused by a change at the other well, because terracing did not change the amount of ground-water recharge upgradient of well LN 1643.

None of the breaks in slope on figures 7.4-33, 7.4-34, and 7.4-35 were statistically significant (at α = 0.05). Breaks in the slope of the double-mass curves were evaluated for statistical significance by use of analysis of covariance procedures detailed in Searcy and Hardison (1960). Analysis of covariance procedures use the F-test, where F is the ratio of among-periods variance to the within-periods of variance. The larger the break in the slope of the double-mass curve, the larger this ratio becomes. Breaks in the slope of double-mass curves become significant when the F ratio exceeds the value of F recorded on a table of the F distribution, which can be found in most statistical texts.

Groups of lysimeters were installed across the site at 3-, 6-, and 9-ft depths to determine soil-water nitrate concentrations in the vicinity of ground-water wells, and were maintained from January 1983 through September 1984. Although most of the lysimeters did not function well, figure 7.4-36 shows the relation between the nitrate concentrations in ground water from well LN 1643 and in soil water from three functional lysimeters near well LN 1643 during the period January 1983 through September 1984. Soil-water nitrate concentrations ranged from less than 1 to 43 mg/L, and were largest at the 9-ft depth. Nitrate concentrations in the soil water fluctuated seasonally; the largest concentrations occurred from October through December 1983--the first major recharge period after the end of the 1983 growing season. This seasonal fluctuation may have been caused by the spreading of manure on fields after harvest and by the leaching of nitrogen left in the soil after the growing season. Ground-water nitrate concentrations at well LN 1643 ranged from 6 to 18 mg/L and increased gradually during the period.

Table 7.4-18.--Examples of residual calculation and cumulative summing of data from well LN 1643 for the 1984 water year

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
Monthly mean water levels	427.5	427.7	429.2	428.3	428.4	428.6	429.2	428.6	428.4	428.6	427.9	427.7
Subtract minimum water table altitude for study periods	-427.1	-427.1	-427.1	-427.1	-427.1	-427.1	-427.1	-427.1	-427.1	-427.1	-427.1	-427.1
Residual	.4	.6	2.1	1.2	1.3	1.5	2.1	1.5	1.3	1.5	.8	.6
Cumulative sums of residuals	.4	1	3.1	4.3	5.6	7.1	9.2	10.7	1	13.5	14.3	14.9

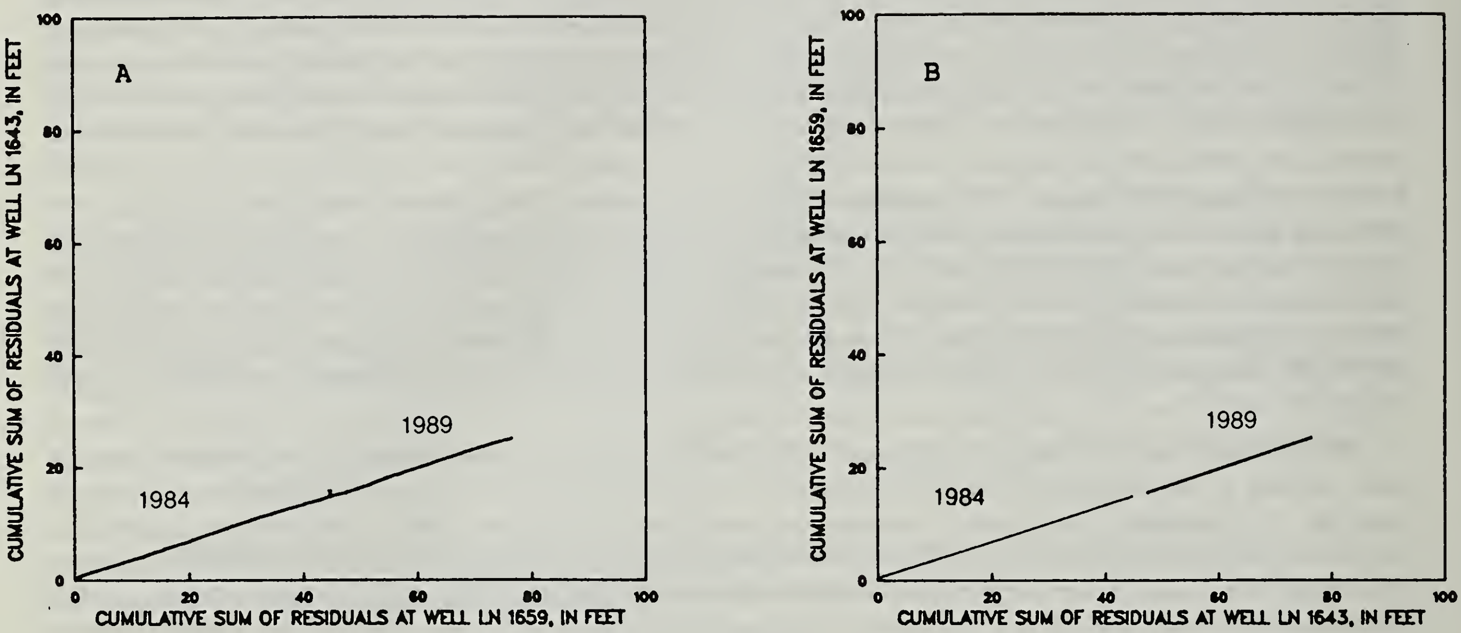


Figure 7.4-33.--Double-mass plot (A) of cumulative residuals and regression (B) of cumulative residuals for the 1984 and 1989 water years for wells LN 1659 and LN 1643.

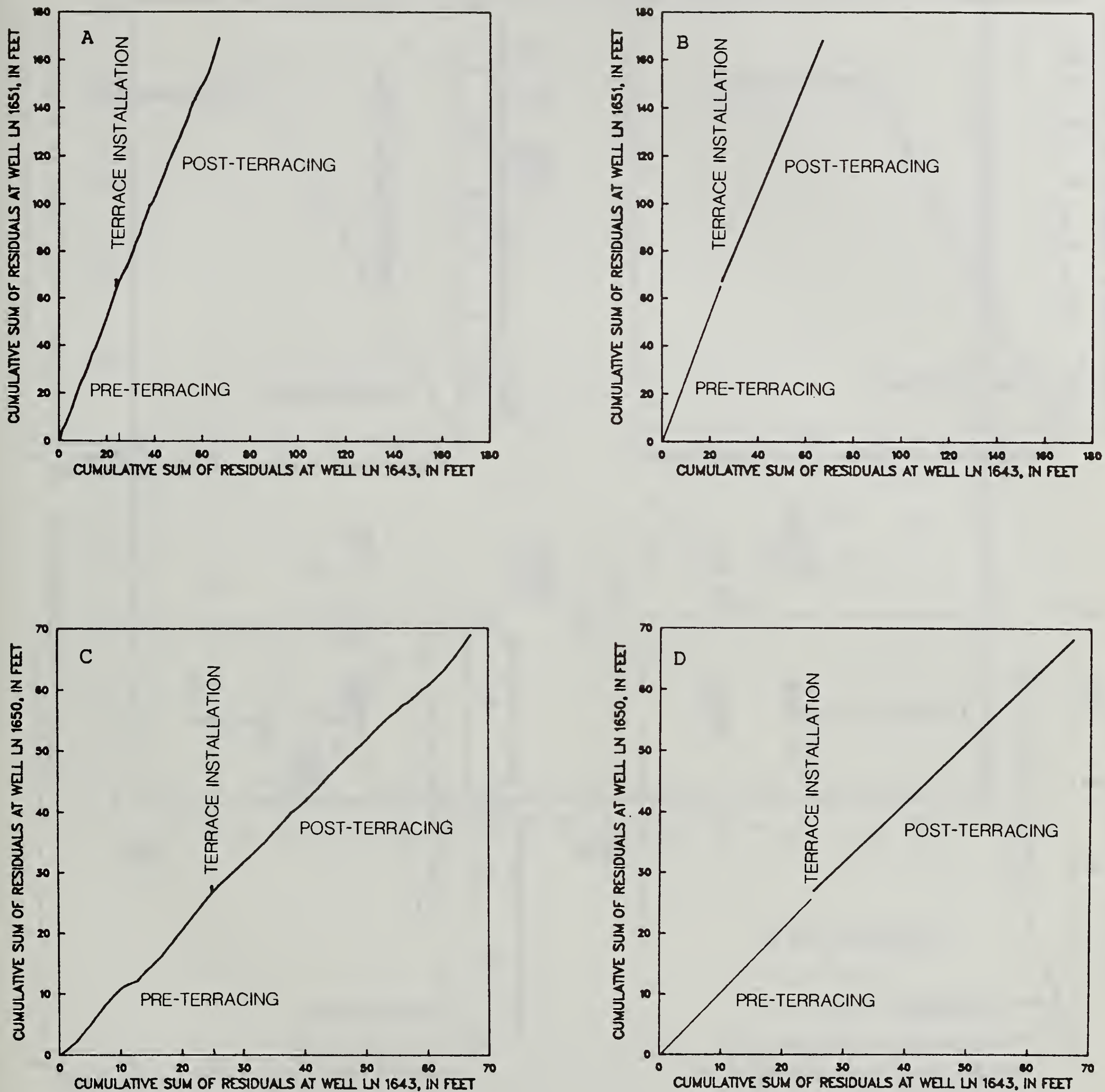


Figure 7.4-34.--Double-mass plots (A and C) of cumulative residuals and regression (B and D) of cumulative residuals for January 1983 through September 1989 at wells LN 1643, LN 1646, and LN 1645.

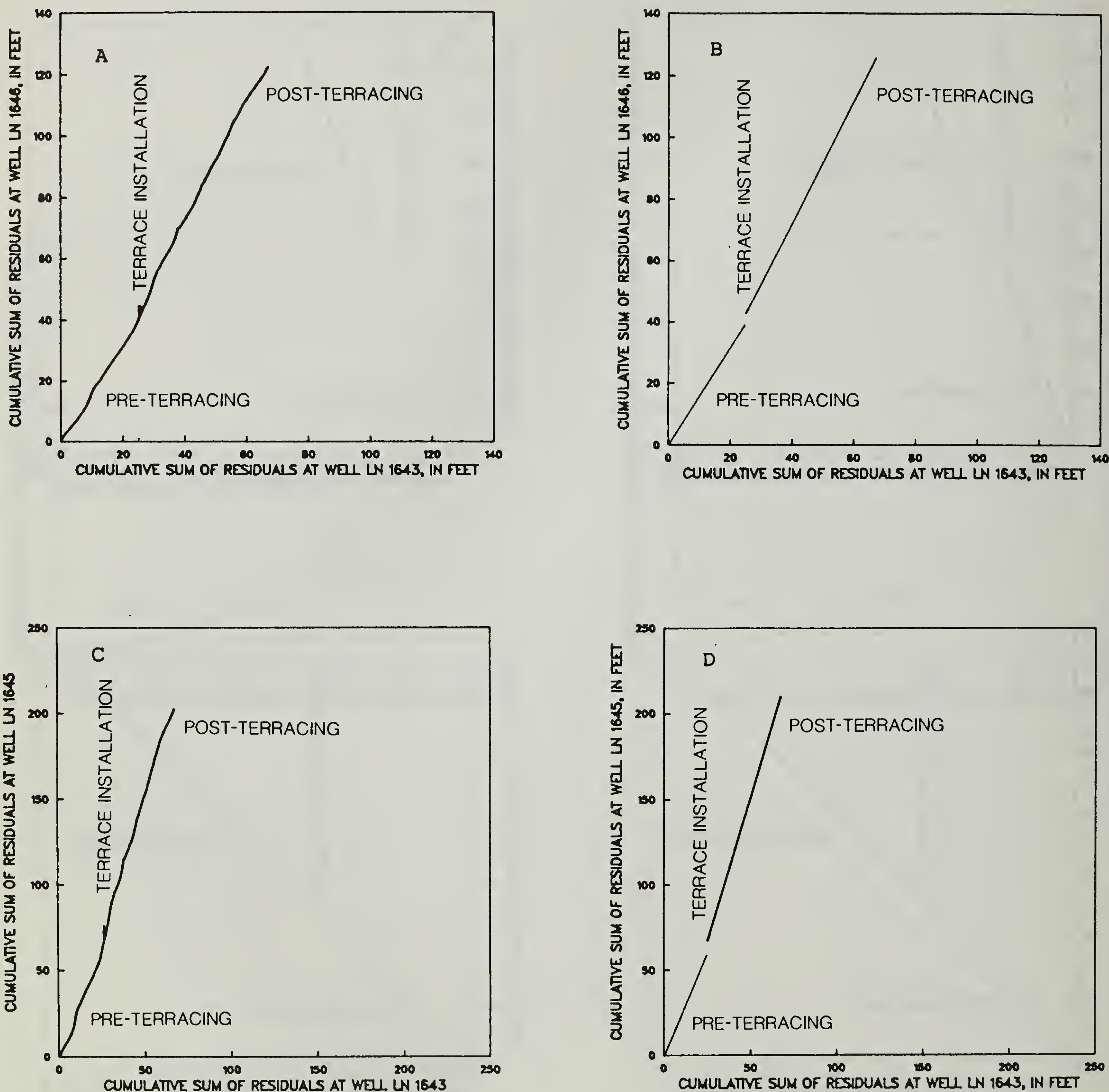


Figure 7.4-35.--Double-mass plots (A and C) of cumulative residuals and regression (B and D) of cumulative residuals for January 1983 through September 1989 at wells LN 1643, LN 1651, and LN 1650.

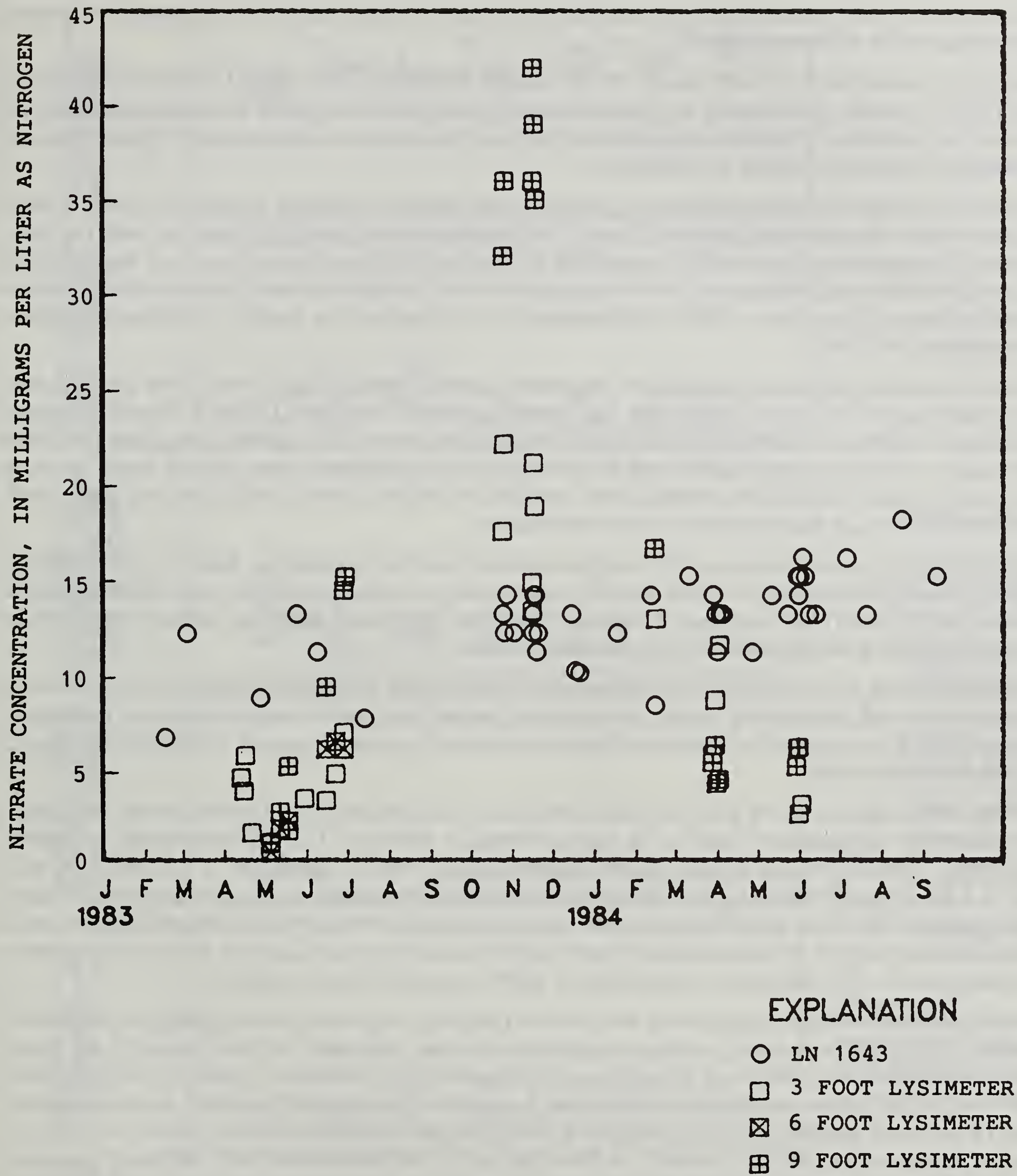


Figure 7.4-36.--Nitrate concentrations in soil water collected in three lysimeters at different depths near well LN 1643 and in ground water from well LN 1643.

Ground-water quality data from samples collected during the study period are represented by annual boxplots in figures 7.4-37 through 7.4-42.

Specific conductances of ground-water at the site ranged from 405 µS/cm at well LN 1646 to 925 µS/cm at well LN 1643. Specific conductance is a measurement of charged ionic species in solution that may be present due to dissolution of site soils, regolith, and bedrock in addition to dissolution of organic material and agricultural chemicals applied to farm fields.

Dissolved phosphorus concentrations in ground-water samples collected during the study period ranged from below the detection limit to 0.11 mg/L as phosphorus in a sample collected at well LN 1651. Phosphorus, like ammonia, is essentially unavailable for leaching to ground water because it rapidly sorbs to soil particles at the land surface and in the unsaturated zone. Phosphorus was therefore determined to be a poor indicator of the effects of BMP implementation on ground-water quality. Phosphorus analyses were discontinued in 1986.

Dissolved organic plus ammonia nitrogen in ground-water samples ranged from below the detection limit to a maximum of 4.6 mg/L as nitrogen in a sample collected from well LN 1643. Organic nitrogen decays through oxidation to ammonium. Ammonia nitrogen concentrations in ground-water samples were small because ammonium ions readily sorb to unsaturated zone materials, and do not easily leach to ground water. Sorbed ammonium subsequently oxidizes to soluble nitrate, which moves easily with infiltration water through the soil column to the water table.

Dissolved nitrite concentrations in 258 analyses ranged from below detection limit to a maximum of 0.38 mg/L in a sample from well LN 1646. Median concentrations of dissolved nitrite were below detection limit in samples collected at all wells and the spring. Nitrite is a short-lived transition product that forms as an intermediate during the oxidation of ammonium to nitrate.

All of the samples were analyzed for dissolved nitrite plus nitrate. Because 99.9 percent of the dissolved nitrite plus nitrate was consistently nitrate, the analyzed nitrate plus nitrite concentrations are referred to as dissolved nitrate for all samples. Dissolved nitrate accounted for over 90 percent of the total nitrogen in the ground water at the site.

Nitrate concentrations in the ground water commonly exceeded the U.S. Environmental Protection Agency maximum contaminant level of 10 mg/L nitrate as nitrogen (U.S. Environmental Protection Agency, 1989). Nitrate-nitrogen sample concentrations ranged from a minimum of 4.8 mg/L at well LN 1646 to a maximum of 33 mg/L at well LN 1643. Dissolved nitrate ions do not sorb to soils and move with infiltration to the water table. Because of the large percentage of total ground-water nitrogen that is nitrate, and the mobility of the nitrate ions in water, nitrate concentrations in ground water were the most appropriate ground-water indicators of the effects of BMPs on ground-water quality.

Assessment of the effects of agricultural activities and recharge on ground-water quality is complicated by a variety of factors. For example, recharge may take a complex path from the land surface to the water table (Priebe and Blackmer; 1989), and ground water in the anisotropic, carbonate aquifer at the site follows complex flow paths that can be difficult to determine. Locations of nutrient and pesticide applications and volumes of materials applied are rough estimates. Bacterial processes that convert organic nitrogen to ammonium and nitrate at the land surface, in the soils, and in the unsaturated and saturated zones are affected by changes in temperature and moisture and by herbicide applications (Stevenson 1982). Despite these complications, important relations between the construction of pipe-outlet terraces and ground-water recharge and surface applied pesticides and nitrogen and water quality are evident in data collected at the site.

The effect of surface-applied materials on ground-water quality at the site during the percolation of recharge water to the water table is exemplified in a graph of atrazine applications and ground-water concentrations over time (fig. 7.4-43). In the 1984 growing season, atrazine was applied at the site on May 23, 1984. At well LN 1645, recharge water delivered atrazine to the water table through approximately 50 ft of soils and weathered material in less than 1 day. Despite no additional applications, atrazine was detected at well LN 1645 through September, suggesting that some of the slow moving recharging waters traveling

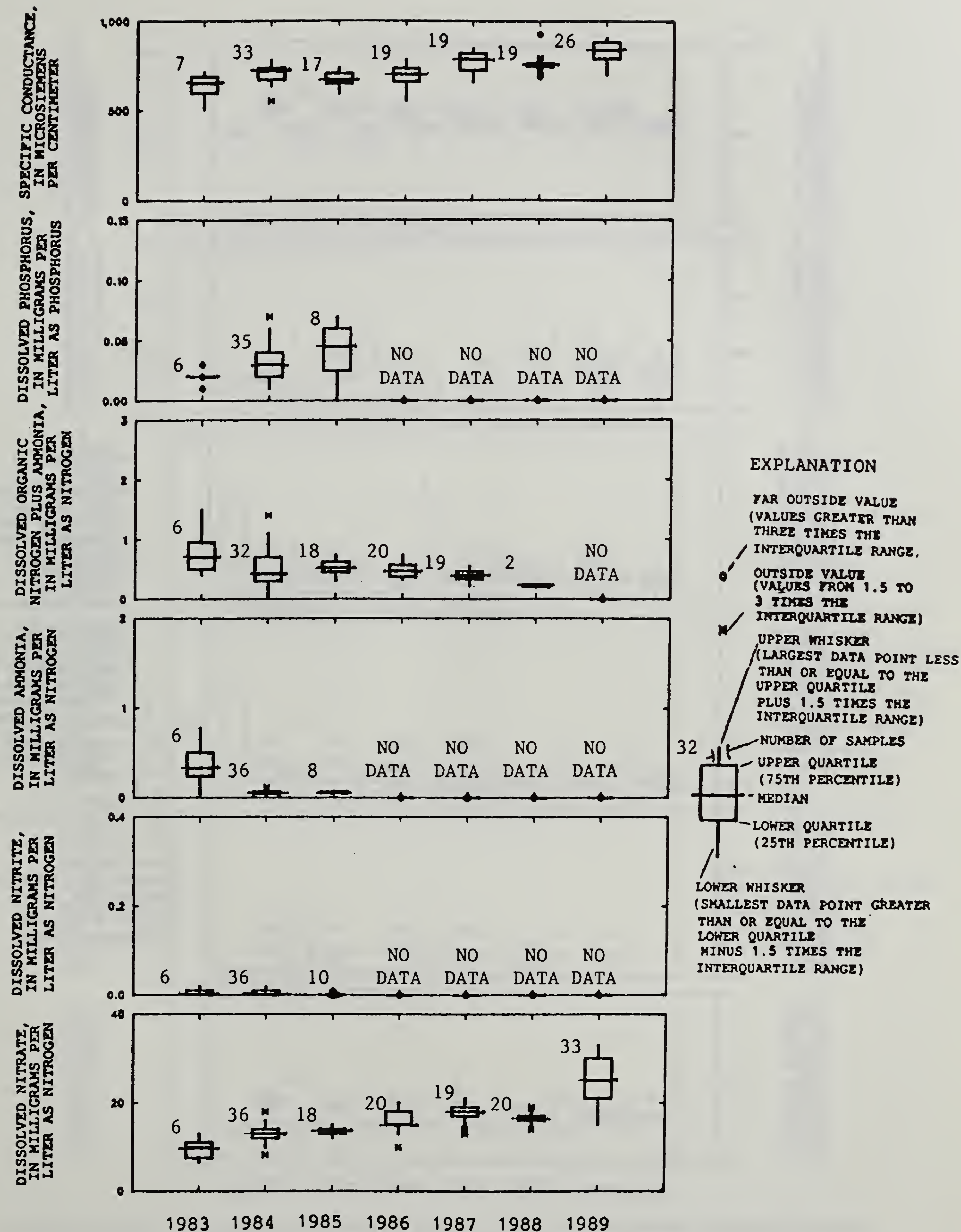


Figure 7.4-37.--Ground-water quality data collected at well LN 1643 during the study period (1983-89).

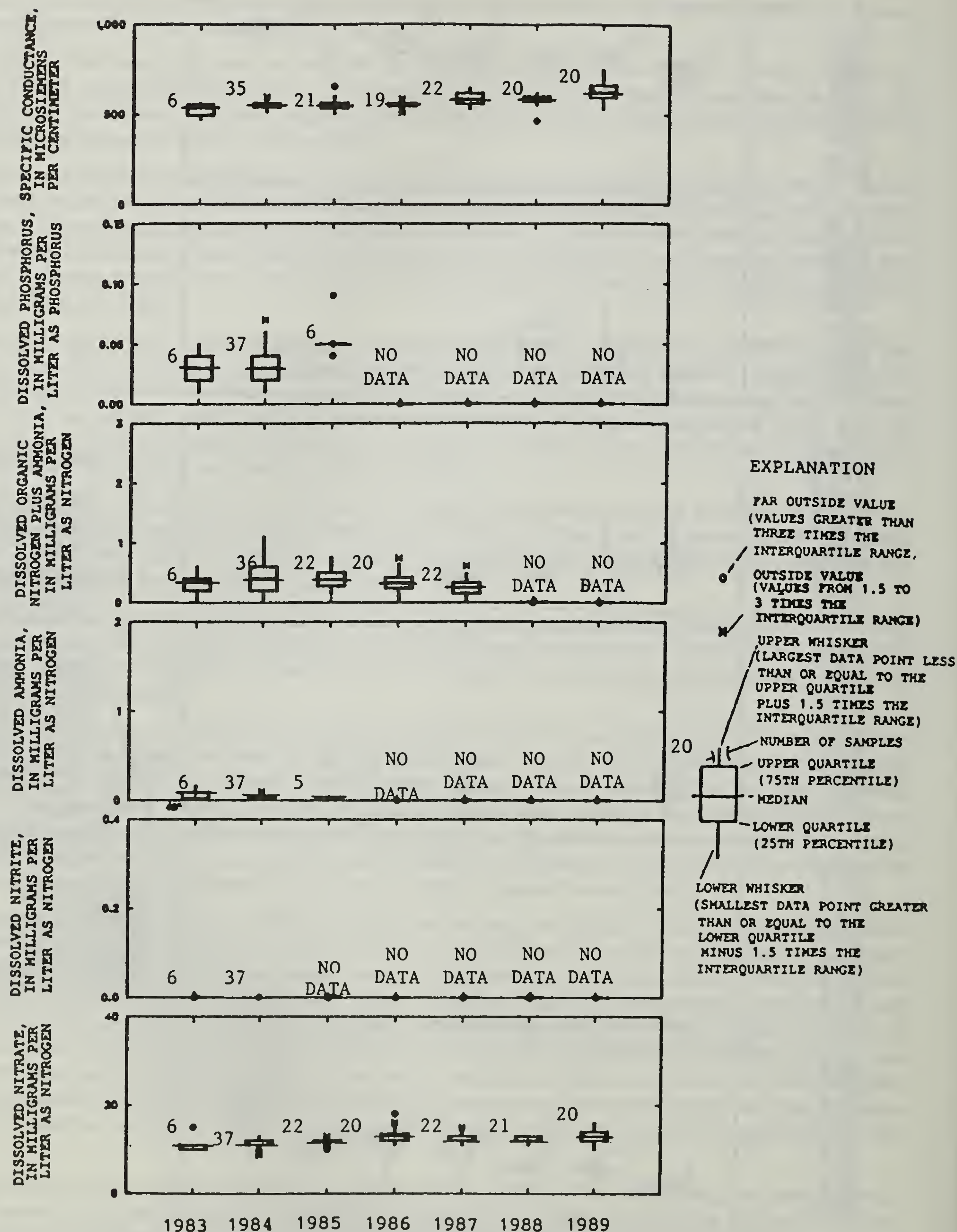


Figure 7.4-38.--Ground-water quality data collected at well LN 1645 during the study period (1983-89).

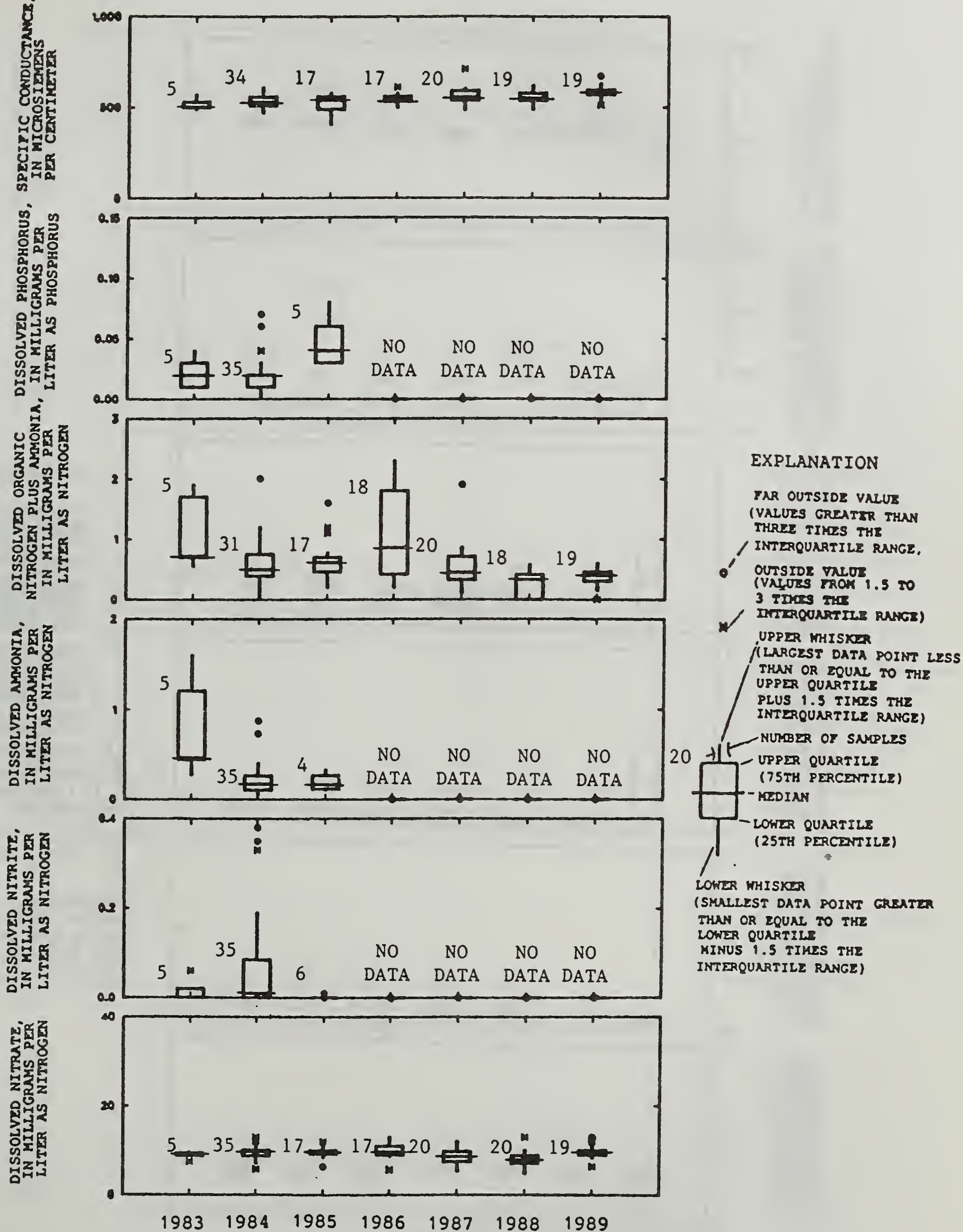


Figure 7.4-39.--Ground-water quality data collected at well LN 1646 during the study period (1983-89).

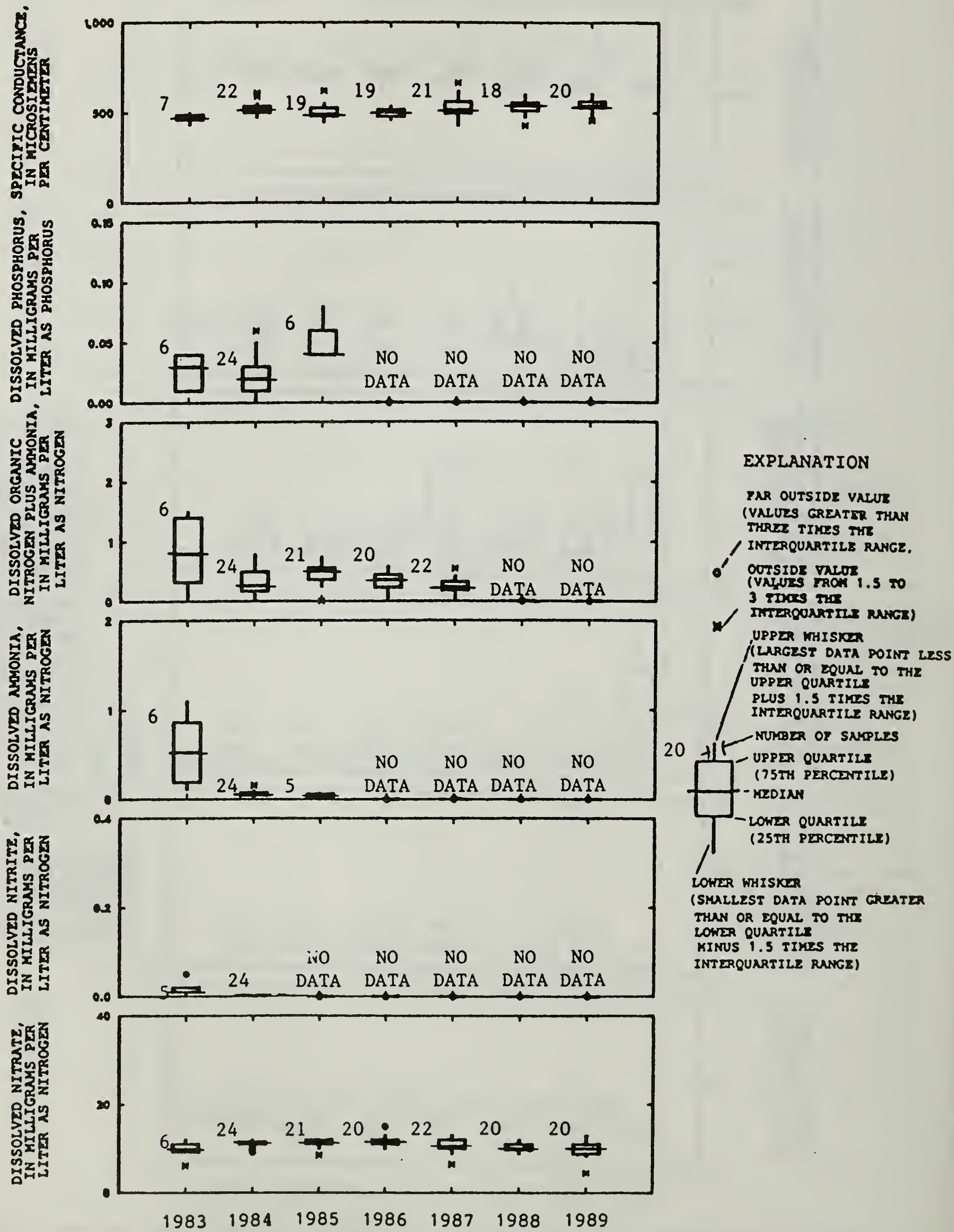


Figure 7.4-40.--Ground-water quality data collected at well LN 1650 during the study period (1983-89).

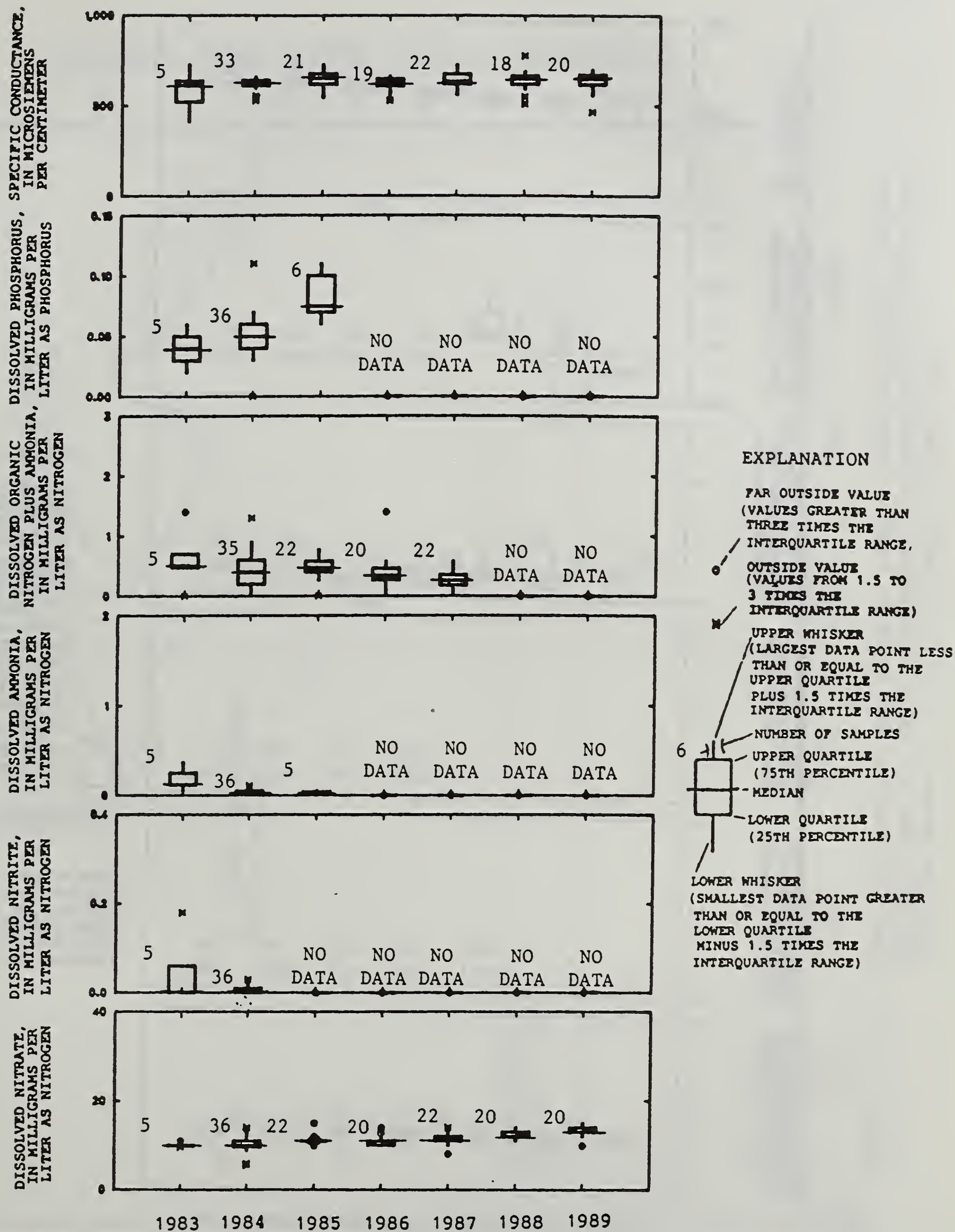


Figure 7.4-41.--Ground-water quality data collected at well LN 1651 during the study period (1983-89).

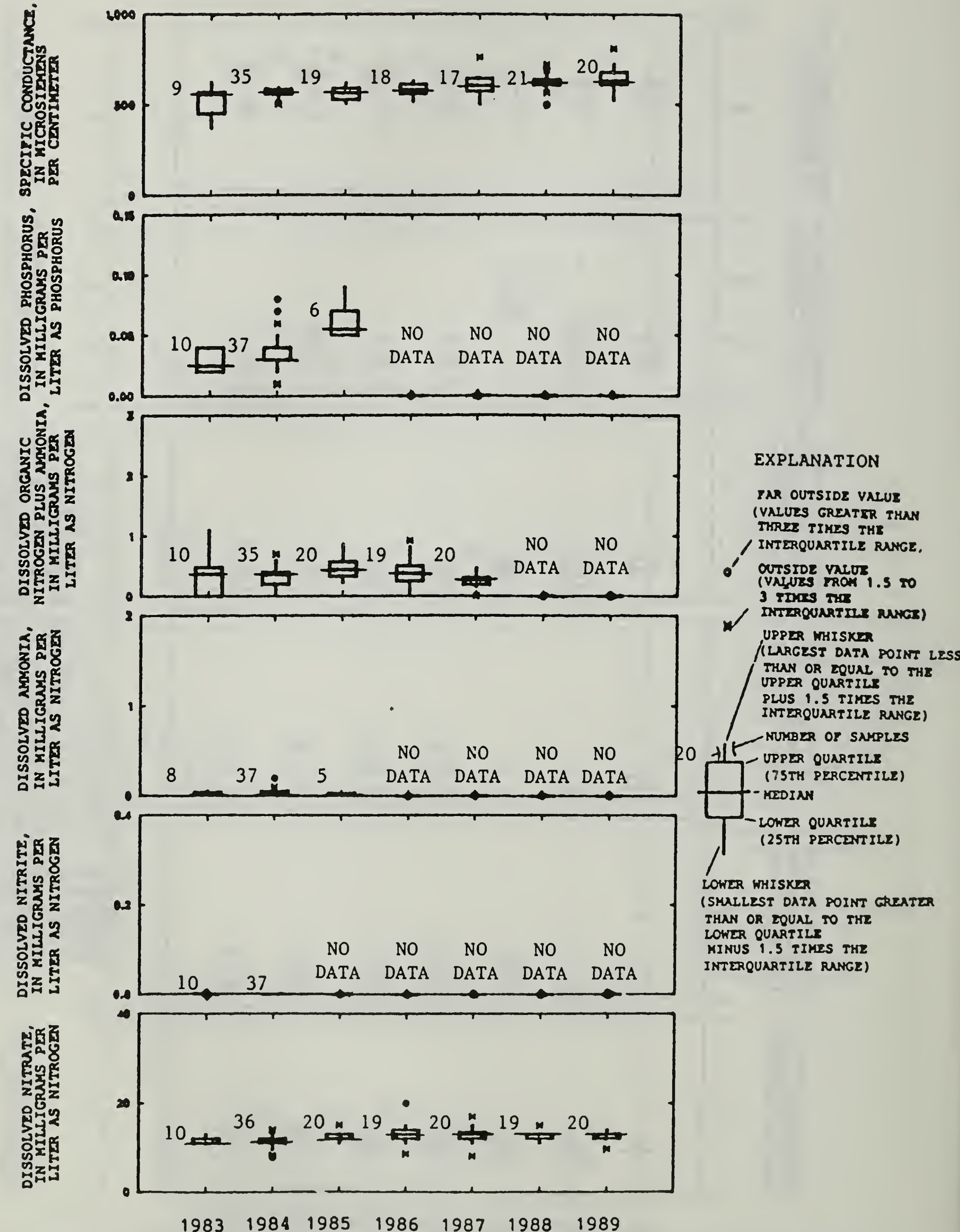


Figure 7.4-42.--Ground-water quality data collected at spring LN SP58 during the study period (1983-89).

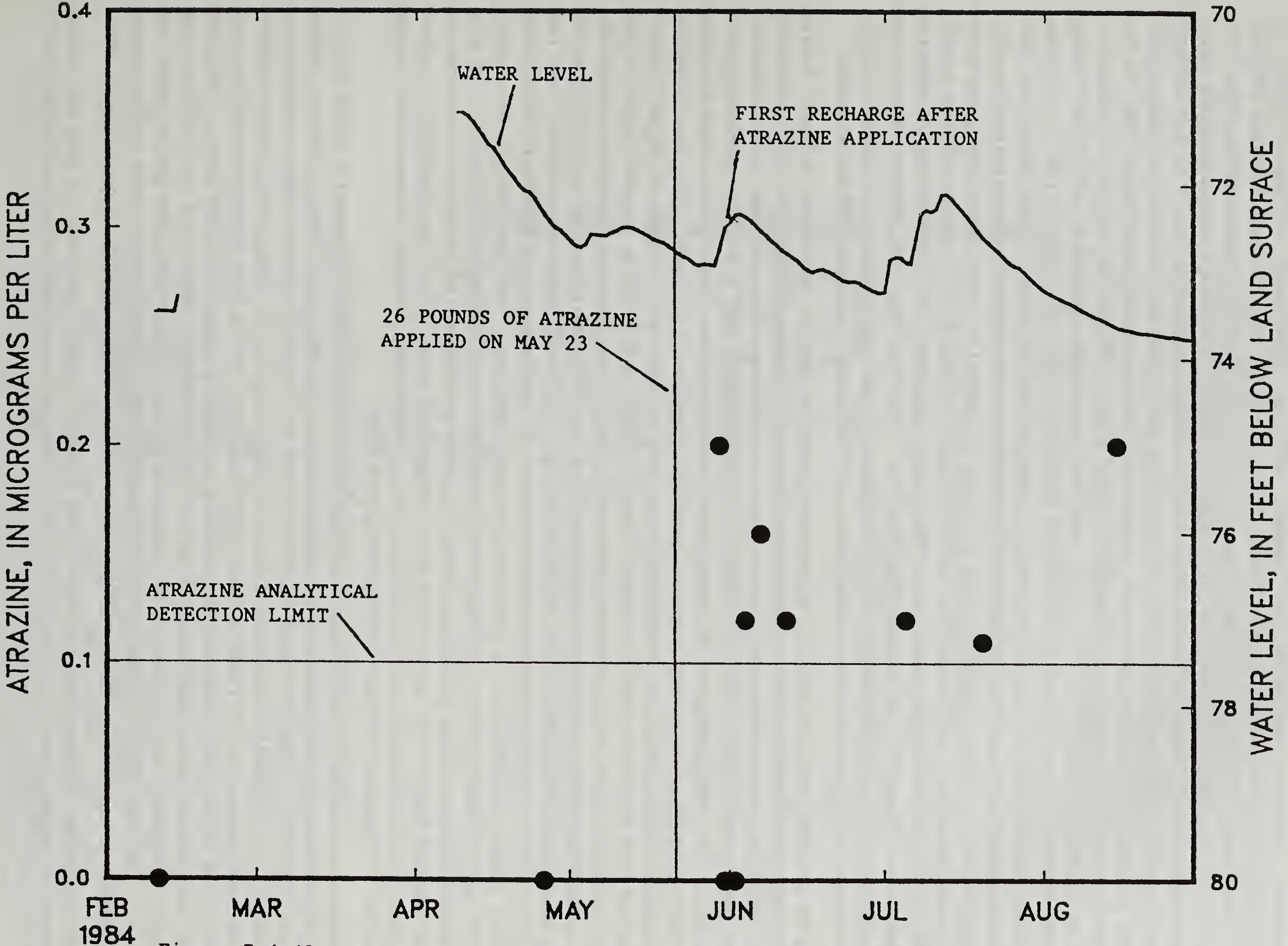


Figure 7.4-43.--Atrazine concentrations in water samples from well LN 1650 before and after May 23, 1984, application. Samples with concentrations below the detection limit are plotted on the X axis.

through the small channels and pores in the unsaturated zone continued to deliver atrazine to the water table (Gerhart, 1986).

Atrazine, cyanazine, metolachlor, and alachlor were the predominant herbicides detected in approximately 250 ground-water samples collected from wells LN 1643, LN 1645, LN 1646, LN 1650, LN 1651, and spring LN SP58 and analyzed for selected triazine and chloroacetinide herbicides (figs. 7.4-44 through 7.4-47). Atrazine, applied to cornfields at Field-Site 1 during each of the 7 years of the study period was detected consistently in ground water. The maximum atrazine concentration was 1.7 µg/L in a sample collected at well LN 1646 during September 1985. Cyanazine was applied to cornfields in the spring of 1987 and 1988. Although sampling for cyanazine in water samples from the site began in January 1983, the first detectable concentrations were found in samples collected in June 1987 after the May 1987 application. A maximum cyanazine concentration of 1.6 µg/L was found in a sample collected at well LN 1645 during June 1988. Metolachlor was applied to cornfields in the spring of each year except in 1987. A maximum metolachlor concentration of 0.6 µg/L was found in a sample collected at well LN 1645 during July 1985. Alachlor was reported to have been applied to Field-Site 1 only in 1981 and 1982, prior to the study period. Although alachlor was not reportedly applied to the site or detected in surface runoff during the study period, it was present at or near the detection limit in 76 percent of ground-water samples collected at wells LN 1645 and LN 1646 during the period April 1986 through September 1989. Alachlor was also found at concentrations of 50 µg/L in a soil sample from Field-Site 1 collected in May 1986. Because alachlor is not commonly found to be persistent in soils and ground water over four-year periods, the presence of alachlor in a soil sample and in ground-water samples from April 1986 through September 1989 is unexplained.

For the pre-BMP period, contributing areas were estimated for the five wells shown in figure 7.4-48 in order to relate ground-water quality to applications of manure and commercial fertilizers. The contributing area to a well is the area of diversion of ground water to the well along with any adjacent surface areas that provide recharge to the aquifer within the area of diversion (Morrissey, 1987, p. 10). The contributing areas for this report were defined using the following methods and assumptions. First, a ground-water-flow path was located (perpendicular to water-table map contours) upgradient of each well. These flow lines were then expanded into wedge shaped contributing areas using an arbitrary 1:1 (roughly 60 degree) ratio of longitudinal flow distance to lateral dispersion (Bouwer, 1978). The true flow to dispersion ratios of this aquifer are unknown as no tracer tests were performed at the site. Some degree of dispersion undoubtedly occurs as materials infiltrate through the unsaturated zone, and additional dispersion (anisotropic) occurs during flow through the aquifer as well. While any nitrogen applications made upgradient of a well can potentially contribute nitrogen in samples collected at that well, applications made closer to the well should contribute greater loads because of dispersion processes associated with flow through the aquifer. Therefore, the contributing areas in this study were defined for the pre-BMP period to delineate a land area of maximum influence, not the total land area that could have any influence on the nitrate concentration of samples collected from a well. Contributing areas changed as a result of terracing changing the surface topography. Contributing areas were not defined for the post-BMP period because the areas would change in response to the amount of terrace ponding during each storm.

Nitrate concentrations in nonrecharge water samples from well LN 1643 appeared to reflect climatic and agricultural-activity changes during the pre-BMP period (D.W. Hall, U.S. Geological Survey, written commun., 1990). From February through May 1983, nitrate concentrations in nonrecharge water samples from well LN 1643 doubled from approximately 6.5 to 13 mg/L (fig. 7.4-49). Nitrogen applications made to the contributing area of well LN 1643 in March, April, and May were at least partially mineralized and nitrified in the warm spring temperatures, providing an available source of soluble nitrate at the land surface before the crops were ready to use it. A series of storms in February, March, and April 1983 provided an effective mechanism for this nitrate to be transported from the land surface to the ground water. The summer of 1983 was dry in the study area. Without recharge to affect ground-water quality, nitrate concentrations in water samples from well LN 1643 showed little change from July through October 1983.

Fall (September, October, and November) 1983 recharge samples from well LN 1643 had nitrate concentrations ranging from 11 to 14 mg/L (fig. 7.4-49). Nitrogen was applied to the contributing area of

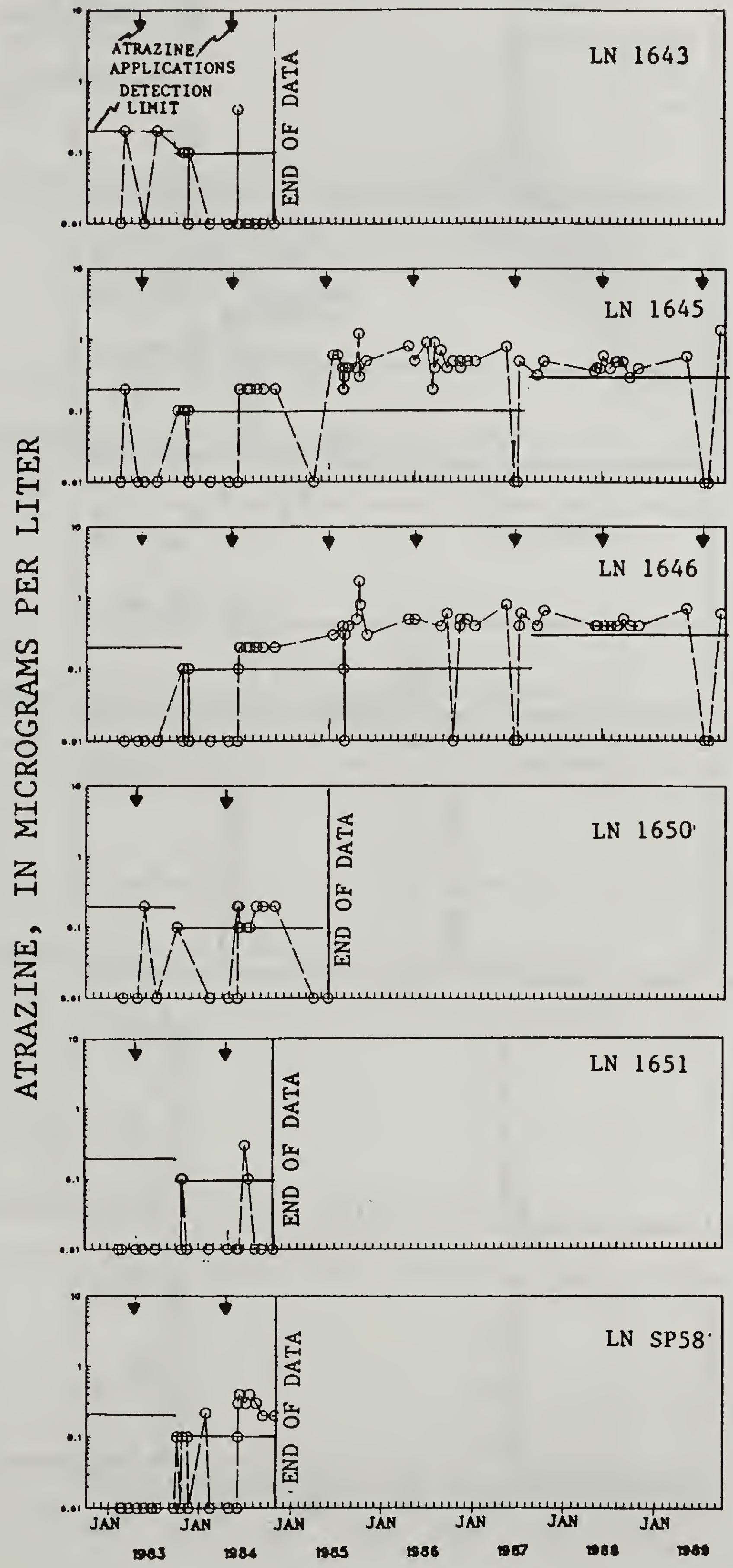


Figure 7.4-44.--Atrazine concentrations in ground-water samples from wells LN 1643, LN 1645, LN 1646, LN 1650, LN 1651, and spring LN SP58.

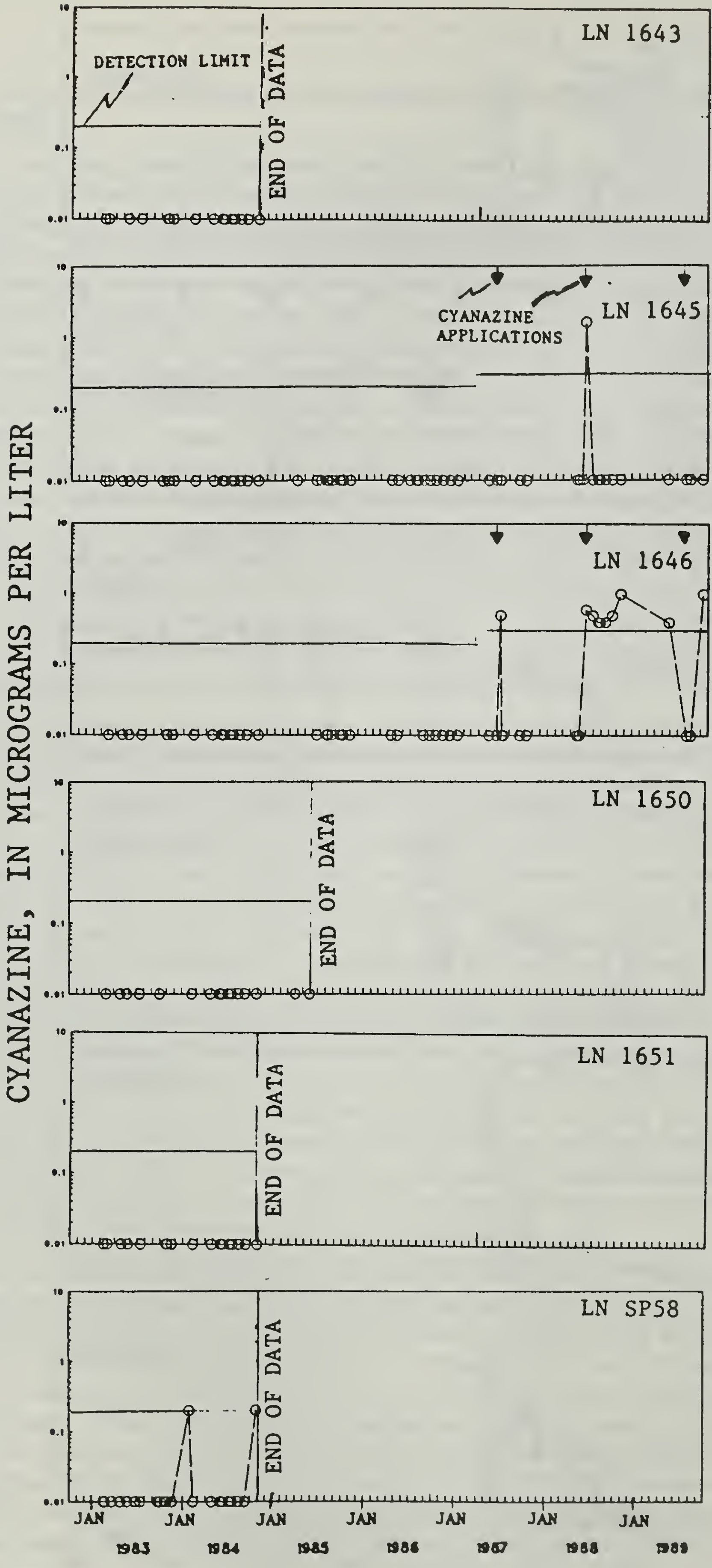


Figure 7.4-45.--Cyanazine concentrations in ground-water samples from wells LN 1643, LN 1645, LN 1646, LN 1650, LN 1651, and spring LN SP58.

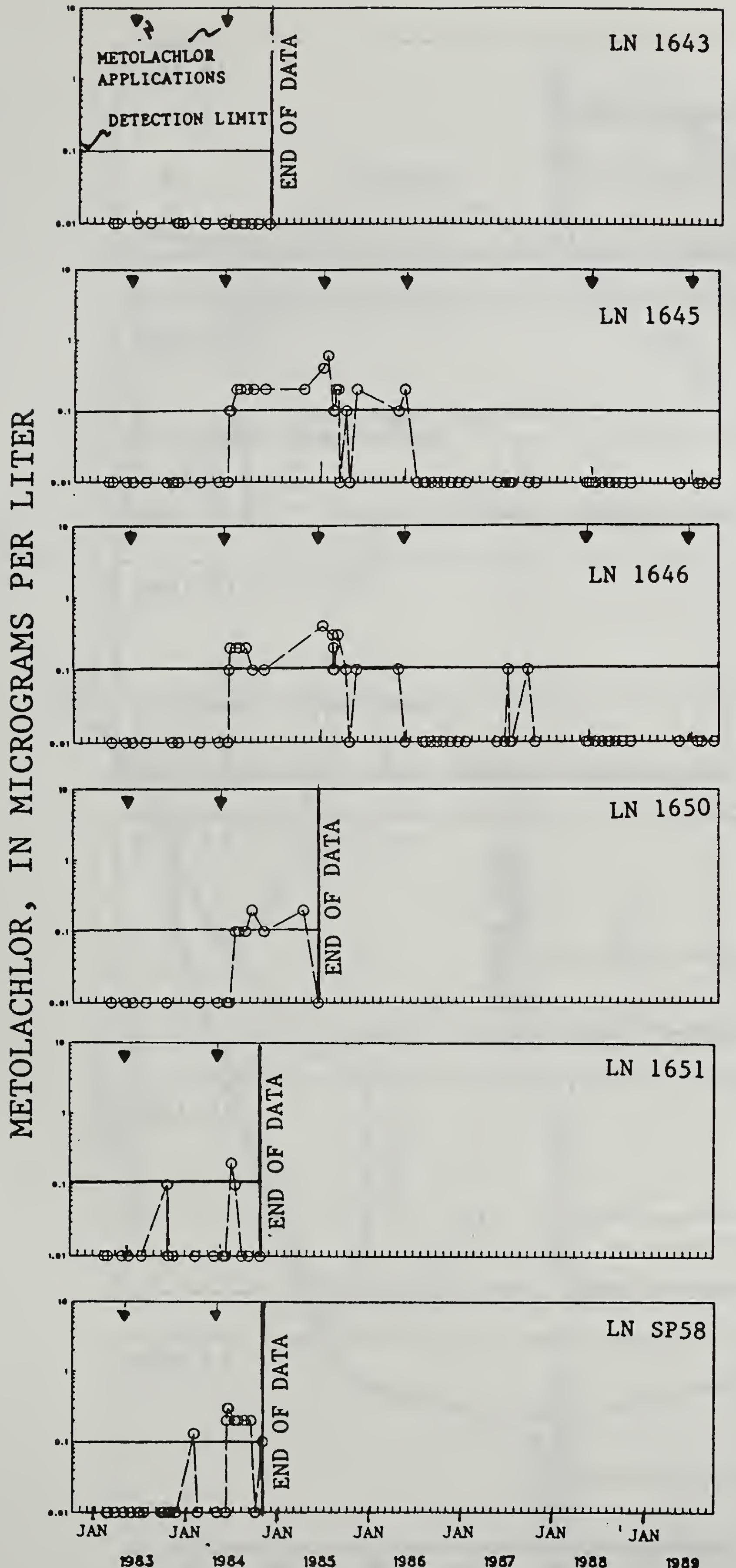


Figure 7.4-46.--Metolachlor concentrations in ground-water samples from wells LN 1643, LN 1645, LN 1646, LN 1650, LN 1651, and spring LN SP58.

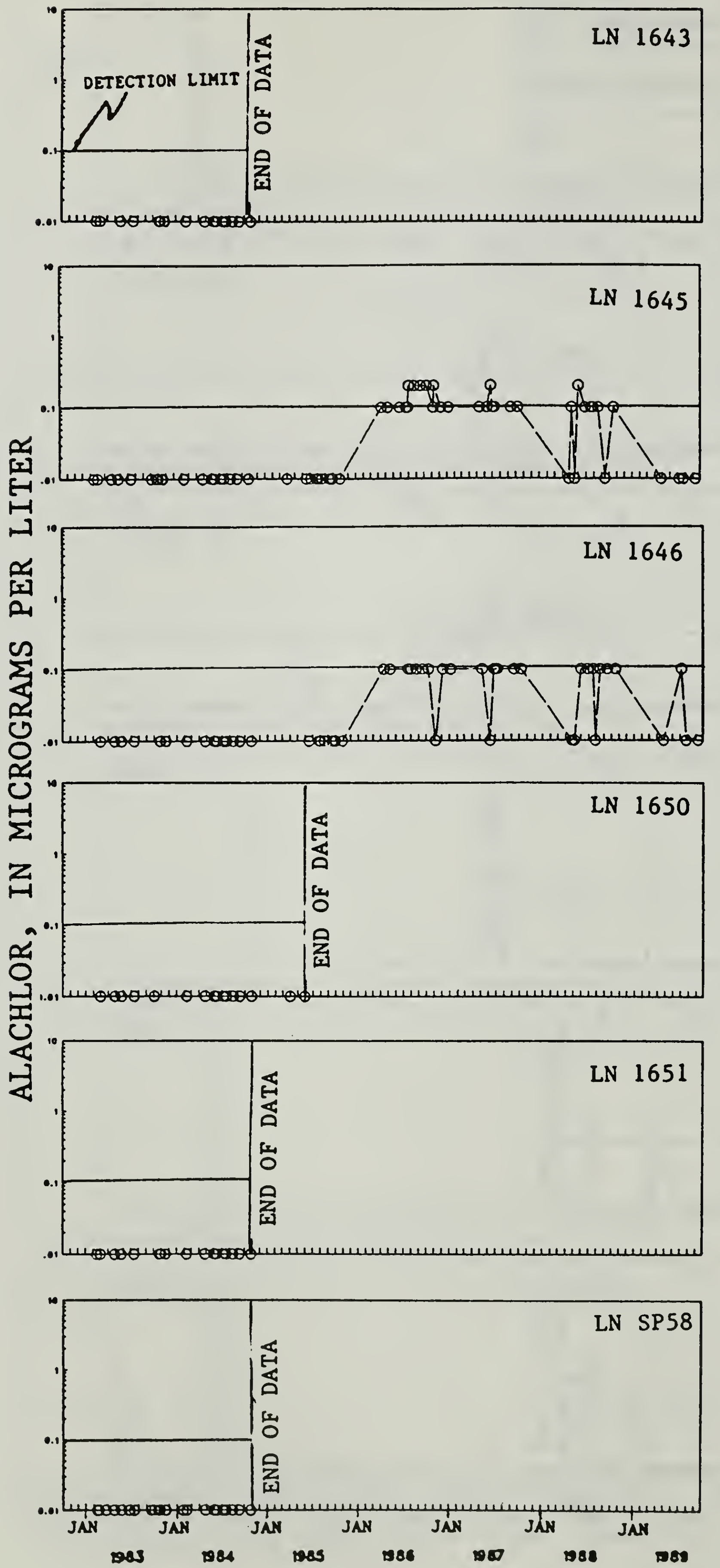


Figure 7.4-47.--Alachlor concentrations in ground-water samples from wells LN 1643, LN 1645, LN 1646, LN 1650, LN 1651, and spring LN SP58.

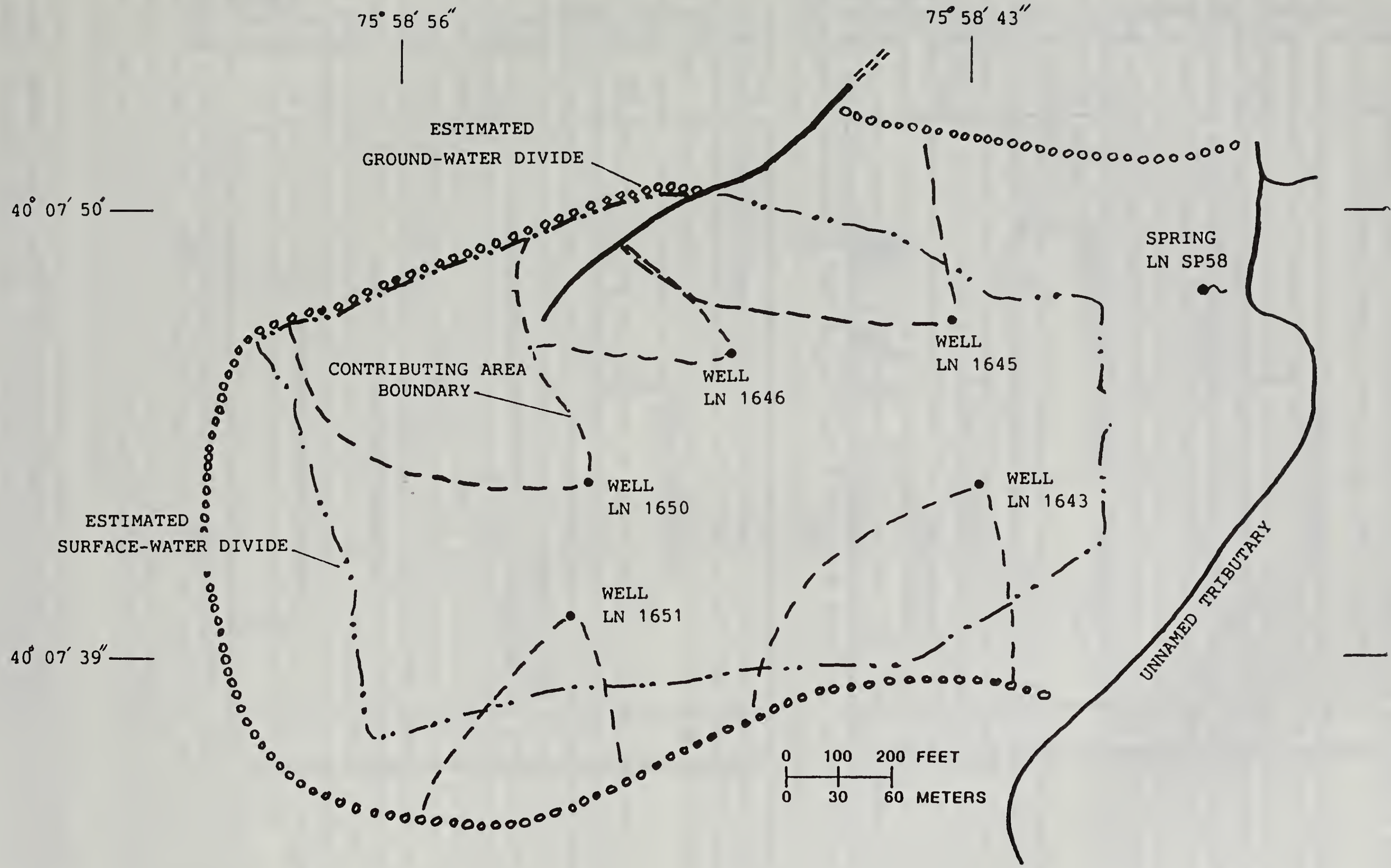


Figure 7.4-48.--Estimated contributing areas for wells in the study area before terracing.

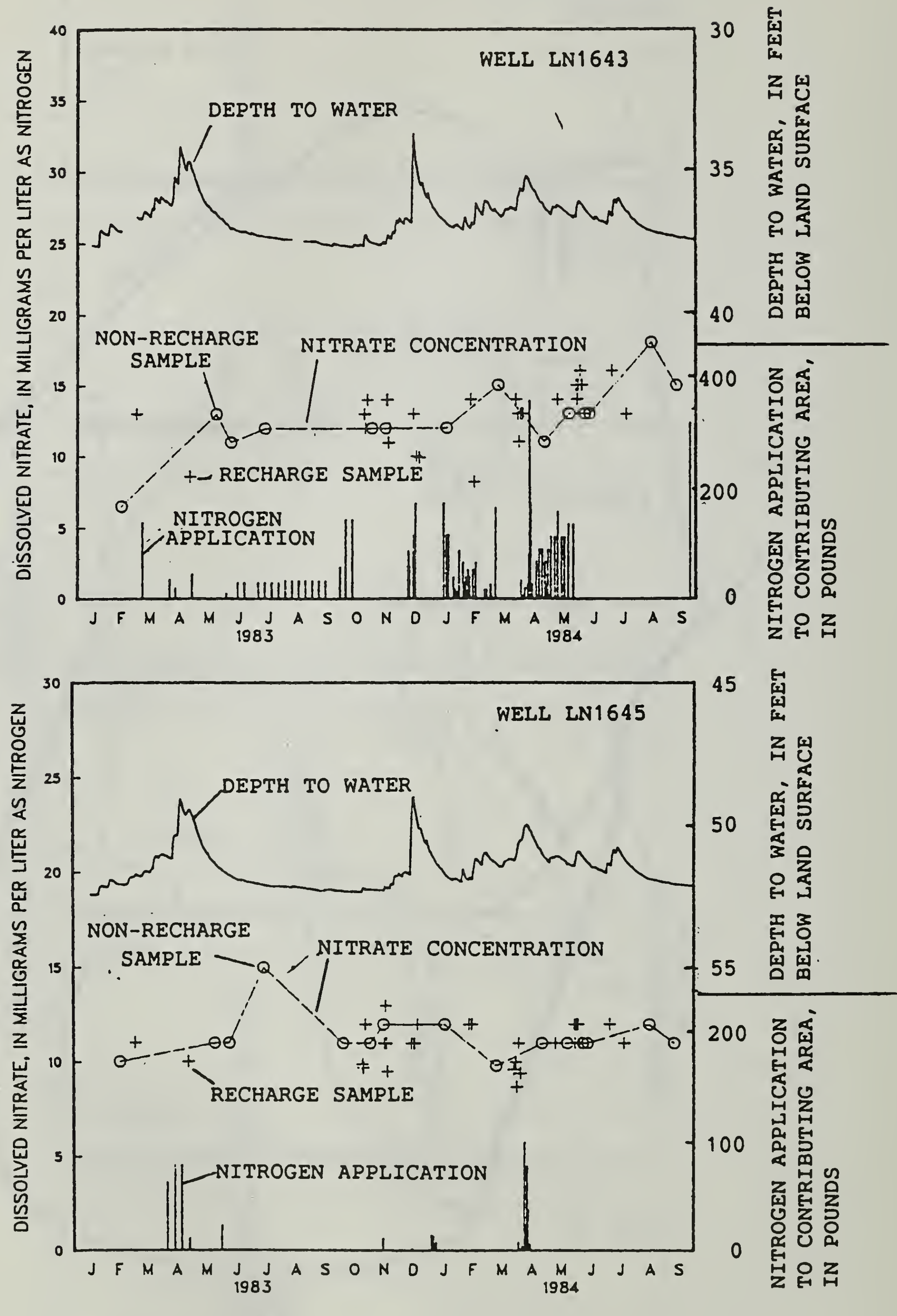


Figure 7.4-49.--Water levels, nitrate concentrations, and nitrogen applications in the estimated contributing areas for wells LN 1643 and LN 1645.

well LN 1643 in late September and early October 1983. There probably was insufficient precipitation during the fall to effect a substantial change in nonrecharge nitrate concentrations.

Winter (December, January, and February) recharge samples from well LN 1643 show the greatest range of nitrate concentrations for any season in the study period–approximately 8 to 14 mg/L (fig. 7.4-49). Although little nitrate was being produced from applied manure because of low temperatures, leaching of nitrates to ground water probably occurred from residual nitrates left in the soil and unsaturated zone from the previous growing seasons. Heavy applications of manure were made to the contributing area of well LN 1643 in December 1983, and in January and February of 1984. This potentially available nitrogen, combined with the large ground-water recharge rates in early December 1983, probably increased the storage of organic nitrogen and ammonium in the soils. Stored nitrogen, together with the heavy spring nitrogen applications and warm temperatures probably contributed to the elevated recharge-sample concentrations in the summer of 1984.

The pre-BMP contributing area to well LN 1645 received fewer nitrogen applications than that of well LN 1643 (fig. 7.4-49). Relations between agricultural activities and quality of water from well LN 1645 were somewhat difficult to discern; however, these relations are probably more typical of the three other wells (LN 1646, LN 1650, and LN 1651 for which pre-BMP contributing areas were estimated) in the study area. Nitrogen-application rates were similar and these four sites generally were affected by the same geochemical processes. Although no specific contributing area was defined for the spring, LN SP58, nitrate concentrations in water from spring LN SP58 appear to be associated with nitrate concentration in water from this group of wells, especially well LN 1651 (as discussed earlier). Nitrate concentrations of recharge-influenced samples from well LN 1645 ranged from 9 to 13 mg/L during the fall of 1983. Most of the measured nitrate probably was caused by leaching of residual nitrate left in the unsaturated zone after the growing season. In November 1983 when precipitation and ground-water recharge increased, leaching probably was accelerated, causing an increase in ground-water nitrate concentrations. Large nitrogen applications were made in the contributing area of well LN 1645 in April 1984, followed by storms which provided recharge. Recharge samples from well LN 1645 collected in May and June had increased nitrate concentrations relative to those collected in April (fig. 7.4-49).

A lag time exists between the time that nutrients are applied at the surface and the time that they are detected in the ground water. The first effects of applications show up as increased nitrate concentrations in ground-water recharge samples collected as soon as several hours after precipitation (Gerhart, 1986). Rapid nitrate transport may be caused by rapid flow through macropores in the unsaturated zone. Nitrate may become available (because of nitrification) in the unsaturated zone during dry periods and accumulate until a recharge event flushes it out. Substantial changes in nonrecharge samples occur over periods of 1 to 3 months, and probably are caused by nitrate loads in slowly moving ground-water recharge traveling through micropores in the unsaturated zone. Micropore recharge has a substantial contact time with soils, and is therefore able to oxidize ammonium and leach nitrate if these species are present in the unsaturated zone. At well LN 1643, there is an apparent 2-month lag between the March 1983 applications and the peak in nitrate concentrations in nonrecharge samples collected in May. A similar lag period of about 3 months was observed between nitrogen applications in April and May 1984 and the nitrate concentration maximum in August 1984 (fig. 7.4-49). At well LN 1645 this lag time occurs between applications of nitrogen during April 1983, and a ground-water nitrate concentration peak 3 months later in July (fig. 7.4-49).

A preliminary qualitative assessment of the effects of BMPs is made below. Documented changes in ground-water quality and corresponding terracing- and agricultural-activity data are used for this assessment. Because of the complex changes that occurred at the site during the study - terracing accompanied, as per USDA-SCS contract, with cropping changes, and changes in nutrient applications from year to year and field to field - and the complex geology of the site, a quantitative determination of the effects of BMPs on ground-water quality was not possible.

The primary influences on changing ground-water quality from the pre-BMP to the post-BMP period were terracing, and the amount and location of nutrients applied to the field. As was shown in this section, the construction of terraces did not significantly change recharge at the site. However, terracing did change the contributing areas of the wells from the pre-BMP period to the post-BMP period.

Nutrient-management recommendations for nitrogen applications to the field (made in 1985), were followed within 25 percent for the 1985, 1986, and 1988 crop years. However, the recommendations were exceeded by about 2.5 times in the 1987 and 1989 crop years. On the average, only about 6 percent less nitrogen was applied to the corn acreage [where most of the manure was applied (table 7.4-3)] after nutrient-management recommendations were made, as discussed in section 7.4.2. Nutrient application characteristics that changed after nutrient management recommendations were made were: (1) the location - applications varied with crop locations (figs. 7.4-4 and 7.4-6); (2) the timing - applications were made somewhat less frequently after implementation, especially during the winter (fig. 7.4-5); and (3) the consistency of some of the manure, which was applied as bedded pack before BMP implementation, and liquid slurry after implementation. While much of the manure was stored in a pit constructed to augment the nutrient-management BMP, heifer manure was spread on the fields as available, as was done during the pre-BMP period.

Time-series plots (1984-89) of nitrate concentrations in ground water at five wells and the spring are shown in figure 7.4-50. These data were divided into four periods to test for statistically significant changes in the median nitrate concentration between periods. The pre-BMP data were included in Period 1 (January 1, 1983 - September 30, 1984). The post-BMP data were divided into three additional periods: Period 2 (October 1, 1984 - September 30, 1986), Period 3 (October 1, 1986 - September 30, 1988), and Period 4 (October 1, 1988 - September 30, 1989).

Ground-water nitrate concentrations increased significantly from Period 1 to each of the post-BMP periods at wells LN 1643, LN 1651, LN 1645, and the spring, LN SP58. No changes were detected at LN 1650, and for LN 1646, no change from Periods 1 to 2 and from 1 to 4, but a statistically significant decrease from Periods 1 to 3 (table 7.4-19).

At Field-Site 1, pre-BMP surface applications of nutrients were shown to affect nonrecharge ground-water quality at wells LN 1643 and LN 1645 from 1 to 3 months after application, as was demonstrated

Table 7.4-19.--Median nitrate concentrations in milligrams per liter as N, in ground water at Field-Site 2 and results of Mann-Whitney testing between Period 1 and post-BMP periods

[Period 1, 1983-84 (pre-BMP); Period 2, 1985-86; Period 3, 1987-88; Period 4, 1989; Post-BMP, 1985-89; ↑, statistically significant increase at the 95 percent confidence interval; ↓, statistically significant decrease at the 95 percent confidence interval; ↔, no statistically significant change]

Well or spring number	Period 1		Period 2		Period 3		Period 4		Post-BMP	
	n	Median concentration	n	Median concentration	n	Median concentration	n	Median concentration	n	Median concentration
LN 1643	18	12.5	21	14.0	22	17.0	11	18.0	54	17.0
LN 1645	18	11.0	22	12.0	24	12.0	11	12.0	57	12.0
LN 1646	17	9.4	21	9.4	23	7.9	11	9.2	55	8.8
LN 1650	15	11.0	22	11.0	23	10.0	9	11.0	54	11.0
LN 1651	17	10.0	22	11.0	23	12.0	11	13.0	56	12.0
LN SP58	16	11.5	18	12.0	20	13.0	11	13.0	49	12.0

	Period 1-Period 2	Period 1-Period 3	Period 1-Period 4	Period 1-Post-BMP
LN 1643	↑	↑	↑	↑
LN 1645	↑	↑	↑	↑
LN 1646	↔	↓	↔	↔
LN 1650	↔	↔	↔	↔
LN 1651	↑	↑	↑	↑
LN SP58	↑	↑	↑	↑

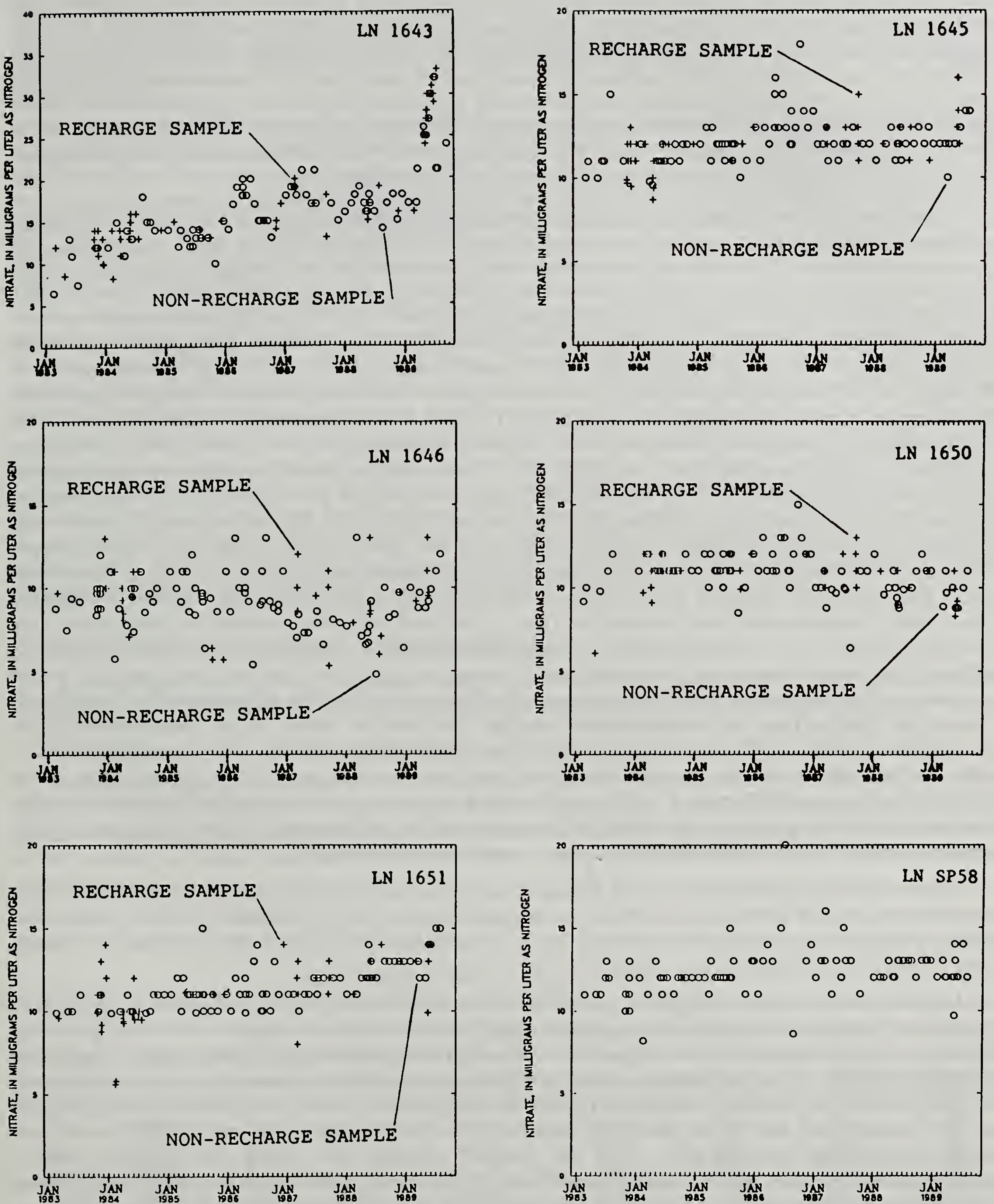


Figure 7.4-50.--Concentrations of recharge and non-recharge nitrate samples collected at wells LN 1643, LN 1645, LN 1646, LN 1650, LN 1651, and concentrations of all nitrate samples collected at spring LN SP58.

quantitatively for Field-Site 2 (see section 7.5.5). However, the change in surface nutrient applications was not the predominant influence on changes in ground-water quality through the post-BMP period. Nutrient applications, except near some of the wells in 1987, generally did not increase from the pre-BMP to post-BMP periods. But, water from three wells and the spring, which is believed to be representative of ground-water quality from the entire site, contained statistically significantly higher nitrate concentrations in the post-BMP period than in the pre-BMP period. In addition, the large increase in nutrient applications for the 1987 crop, made primarily to fields 2, 3, and 4 in the spring of 1987, was not reflected by a large change in ground-water quality at any of the wells near the time of application (fig. 7.4-3).

It is believed that the increase in ground-water concentrations of nitrate at the three wells and the spring may have resulted from increased nitrate concentrations in infiltrating water as a result of terracing. This hypothesis is supported by evidence from surface-runoff data from the site. During the post-BMP period, nitrate plus nitrite comprised a larger portion of the total-nitrogen load in runoff relative to the pre-BMP period; 35 percent and less than 10 percent, respectively (table 7.4-6). Nitrate concentrations in surface-runoff were significantly higher during the post-BMP period than during the pre-BMP period. The nitrate + nitrite concentration in runoff during the pre-BMP period ranged from 0.01 to 8.7 mg/L with a median of 0.50 mg/L for 421 instantaneous samples, and the nitrate + nitrite concentration during the post-BMP period ranged from 0.14 to 45 mg/L with a median of 1.6 mg/L for 634 instantaneous samples. The surface-runoff samples at the beginning of the event and near or at the end of the event with the lowest discharges contained the highest concentrations of nitrate during the post-BMP period. (This also occurred at Field-Site 2, which was also terraced.) During the pre-BMP period, runoff with low velocities, such as snowmelt, contained higher concentrations of dissolved nitrogen than runoff with high velocities and similar field conditions. Higher nitrate concentrations in surface runoff near the end of the storm, when discharges are low, support the hypothesis that leachate contained higher nitrate concentrations during the post-BMP period than during the pre-BMP period when no terracing was in place. Terracing resulted in extended contact time of surface runoff and leachate with the nutrient-rich soils, thus, increase in dissolution of the available nitrate can occur and nitrification rates may increase. Nitrate concentrations in runoff were as high as 29 mg/L at the end of one storm, but varied greatly throughout the study. Leachate concentrations would be expected to be even greater than runoff concentrations because the leachate samples were in contact with a larger soil profile than the surface-runoff samples. The median values of the mean-storm nitrate concentrations within the clusters of similar type storms increased 2 to 9 fold from Period 1 to Period 3 (table 7.4-13). Additionally, many storms which produced runoff during the pre-BMP period produced no runoff during the post-BMP period, which may have led to an increase in infiltration through micropore flow and higher soil moisture levels although the quantity of this infiltration would not be expected to be substantial enough to be observable by analysis of water-level hydrographs.

Because infiltrating micropore as well as macropore water has greater contact time with nutrient rich soils than does runoff water, it is reasonable to conclude that a 1.5 mg/L increase in median nitrate plus nitrite concentrations in runoff after terracing would be correlated with a 1 to 4 mg/L increase in ground-water nitrate concentrations.

Another indication that changes in surface-runoff concentrations may be indicative of changes in ground-water concentration is that during the post-BMP period, nitrate concentrations in runoff generally increased at low discharges near the end of the storm except from July through October when the response was highly variable. A cyclical pattern of changes in ground-water nitrate concentrations observed at well LN 1643 were similar. Generally, increases in nitrate concentrations occurred throughout the year, except in the late summer and fall, when decreases occurred. The cyclical pattern at well LN 1643 was more pronounced during the post-BMP than the pre-BMP period, and during the pre-BMP period, concentrations of nitrate + nitrite in surface runoff were highly variable during low discharges near the end of the storms, except in May and June when samples during these conditions generally had higher nitrate concentrations than other samples collected during the storms.

Where there was a substantial change in nitrogen applications in a particular area of the site, changes were also found in ground-water nitrate concentrations. As a result of cropping changes, the proportion of alfalfa grown upgradient of wells LN 1646 and LN 1650 increased (fig. 7.4-4). Generally, nutrient applications to alfalfa were substantially less than applications to corn (table 7.4-3). Ground-water

concentrations of nitrate in water from wells LN 1646 and LN 1650 were not significantly different from the pre-BMP to post-BMP periods (fig. 7.4-50), except from Period 1 to 3 when a significant decrease was detected at LN 1646 (fig. 7.4-50). A combination of cropping changes resulting in substantial reductions in the nutrient applications upgradient of these wells, probably caused a reduction in the ground-water nitrate concentrations.

In the spring of 1989, there was a substantial increase in nitrate concentrations in nonrecharge samples at LN 1643, and smaller increases in concentrations in samples from some of the other wells (fig. 7.4-50). By July and again in September concentrations of nitrate returned to near the levels measured earlier. Although there was an extremely large application of manure made to Field 7 in December of 1988, over 2000 lb/acre as N, it is not known if this activity directly affected the nitrate concentrations in the well water, but the increase in the concentration of nitrate at LN 1643 cannot be explained by any of the other available agricultural-activity data.

In summary, the ground-water quality at Field-Site 1 was affected by agricultural practices, although ground-water quantities were not substantially affected by terracing. On the basis of preliminary data analysis, a qualitative assessment of data collected from the site shows that the nitrate concentration of recharge water is impacted by available nutrients at or near the surface. There is qualitative evidence provided by changes in runoff characteristics and surface-water quality data that the significant increases in ground-water nitrate concentrations from the pre-BMP to the post-BMP period at four of the ground-water sampling locations, was attributable to increased nitrate concentrations in recharge as a result of terracing which allowed increased contact time of runoff and recharge water with nutrient-rich soils. There is also qualitative evidence that large decreases in nutrient requirements and applications due to a crop change from predominantly corn to alfalfa upgradient of two of the wells masked the effects of terracing on water quality, and resulted in either no detectable change or a significant decrease in ground-water nitrate concentrations from the pre-BMP to the post-BMP period.

7.4.6 Field-Site 1 Hydrologic and Nitrogen Budgets

A preliminary analysis of the water budget for Field-Site 1 (table 7.4-20) was estimated from measurements of runoff and estimates of ground-water recharge using the following equation:

$$\text{precipitation} = \text{runoff} + \text{ground-water recharge} + \text{evapotranspiration} + \text{change in storage} \quad (10)$$

Runoff and recharge were probably underestimated during winter months, causing an overestimated amount of evapotranspiration. Runoff from slowly melting snow cover was largely unmeasured. In addition, water that would under warmer conditions either runoff or recharge the ground water, was held at the surface as snow until the following month, which introduced some error into the monthly calculations.

Table 7.4-20.--Water budget for Field-Site 1

Pre- or post-terracing	Water year	Total precipitation, in inches	Runoff, in inches	Percent of total precipitation	Ground-water recharge, in inches	Percent of total precipitation	Evapo-transpiration, in inches	Percent of total precipitation
Pre-	1983[1]	31.4	1.1	4	14.7	47	15.6	49
Pre-	1984	59.8	7.9	13	25.0	42	26.9	45
Post-	1985	41.7	6.7	16	12.0	29	23.0	55
Post-	1986	35.6	4.9	14	11.1	31	19.6	55
Post-	1987	46.2	5.2	11	17.2	37	23.8	52
Post-	1988	41.3	6.0	15	15.3	37	20.0	48
Post-	1989[2]	39.6	1.6	4	14.9	38	23.1	58

[1]January 1, 1983, through September 30, 1983.
[2]October 1, 1988, through July 31, 1989.

The ground-water-flow system was assumed to be closed to inputs except recharge from precipitation. The amount of ground-water recharge at the site was estimated using data collected at well LN 1643. This well was chosen because a continuous record of water-level data was available. Because precipitation infiltrates quickly to the water table upgradient of LN 1643, water-level rise multiplied by the specific yield (0.13) gave a reasonable estimate of ground-water recharge for any storm. Hence, monthly recharge was estimated by summing water-level rises occurring during each month and multiplying the sum by the median specific yield of 0.13.

Ground-water discharge from the site was estimated by multiplying the annual recharge times the drainage area. It was also assumed that annual recharge entering the site approximated annual discharge leaving the site.

Total monthly discharge computed for the site were based on data from LN 1643 because this well was closest to the discharge area of the basin (water-table contours in figure 7.4-26 indicated that most of the discharge occurred near this well), and the water-level record for the study period was nearly complete. Annual ground-water discharge from Field-Site 1 was prorated, by month, using Darcy's Law. The hydraulic gradients controlled the discharge at Field-Site 1. Monthly change in water level at well LN 1643 was determined by subtracting the lowest water-level elevation recorded during the entire study period (1983 through 1989) from each monthly-mean water level. Proportional monthly changes in water level were then multiplied by annual recharge to estimate monthly discharges. An example of estimated monthly ground-water discharge from the site during the period January 1983 through August 1989 is illustrated in table 7.4-21.

For the five complete years of record 1984-88, precipitation quantity ranged from 35.6 inches (1986) to 59.8 inches (1984), runoff as a percent of precipitation ranged from 11 percent (1987) to 16 percent (1985), ground-water recharge as a percent of precipitation ranged from 31 percent (1986) to 42 percent (1984), and evapotranspiration as a percent of precipitation ranged from 45 percent (1984) to 55 percent (1985 and 1986).

The numbers presented in this budget are estimations, and are subject to errors of unknown magnitude in measurements collected at the site and in errors of unknown magnitude in assumptions used to make calculations. Additionally, proportional changes in annual runoff, recharge, and evapotranspiration could occur in response to variable climatic factors including timing of precipitation, air temperature, proportion of annual snowfall and rainfall, cropping patterns, and tillage, which could obscure any changes in the budget caused by terracing. However, the budget is probably accurate enough to state that no extreme changes in site hydrology occurred as the result of terracing. Surface runoff was of approximately the same

Table 7.4-21.--Estimated monthly ground-water discharge from Field-Site 1

[All values are in cubic feet; --, no data]

Month	Water year 1983	Water year 1984	Water year 1985	Water year 1986	Water year 1987	Water year 1988	Water year 1989
October	--	70,000	88,000	65,000	41,000	98,000	69,000
November	--	93,000	86,000	65,000	74,000	101,000	108,000
December	--	267,000	92,000	104,000	154,000	97,000	88,000
January	59,000	162,000	86,000	77,000	167,000	98,000	88,000
February	118,000	174,000	108,000	130,000	144,000	158,000	88,000
March	189,000	197,000	93,000	127,000	173,000	114,000	127,000
April	283,000	267,000	73,000	92,000	133,000	87,000	118,000
May	200,000	197,000	86,000	73,000	109,000	106,000	186,000
June	118,000	174,000	82,000	60,000	109,000	88,000	196,000
July	83,000	197,000	68,000	50,000	101,000	118,000	177,000
August	71,000	116,000	77,000	51,000	80,000	124,000	118,000
September	59,000	93,000	64,000	37,000	151,000	92,000	--
Annual discharge	1,180,000	2,007,000	1,003,000	931,000	1,439,000	1,281,000	1,363,000

order of magnitude and range as runoff quantity that occurred prior to terracing of the site. Although the budget can not be used to gage any small effects of terracing on the quantity of evapotranspiration at the site, the budget suggests that pooling of water on terraces did not cause extreme increases in quantity of evapotranspiration.

A simplified nitrogen balance for Field-Site 1 was determined for the period January 1983 through September 1984 using measured and estimated values for inputs and outputs of nitrogen (fig. 7.4-51) (D.W. Hall, U.S. Geological Survey, written commun., 1990). Major inputs of nitrogen to Field-Site 1 include manure and commercial fertilizer applications and nitrogen in precipitation. Applications made to the site as reported by the farmer included about 11,500 lb of nitrogen from manure and 600 lb of nitrogen from commercial fertilizer, together accounting for 98 percent of the total input of nitrogen. Nitrogen inputs from precipitation were estimated to be about 300 lb (2 percent).

Outputs of nitrogen for the period January 1983 through September 1984 included: (1) 2,400 lb discharged by the ground-water-flow system, or 20 percent of the total nitrogen output; (2) 300 lb (2.3 percent) transported with surface runoff; (3) 4,700 lb (39 percent) volatilized from manure; and (4) 4,600 lb removed in harvested crops (38 percent).

Total monthly ground-water nitrogen loads were estimated based on data from well LN 1643. Estimated monthly ground-water discharges (table 7.4-6) were multiplied by the median nitrate concentration of all nonrecharge and recharge samples collected in each month to derive nitrogen loads in ground-water discharge (fig. 7.4-52).

For the period January 1983 through September 1984, approximately 2,400 lb of nitrogen discharged with ground water from the study area. (For all ground-water samples from the pre-BMP period, dissolved nitrate accounted for 93 percent of the total nitrogen, and therefore nitrate ground-water concentrations are used to calculate estimated nitrogen loads in this budget). The average monthly nitrate load from the site, estimated using data collected at well LN 1643, was approximately 110 lb; the average daily load was approximately 4 lb. This amounts to approximately 60 (lb/acre)/yr of nitrogen discharged through the ground-water-flow system. The nitrogen load at well LN 1645, which is located slightly north of well LN 1643 was also about 60 (lb/acre)/yr.

The 40 percent value used for losses of nitrogen from volatilization was estimated based upon surface-spread, nonincorporated manure applications made at the site in conjunction with estimates of manure volatilization contained in the PaDER Field Application of Manure manual (Graves, 1986). Rates of nitrogen volatilization from manure range from 0 to greater than 90 percent as a function of manure type, precipitation, soil moisture, soil pH, temperature, wind velocity, humidity, and time until incorporation into the soil.

The harvesting of the corn removed approximately 4,300 lb of nitrogen, based upon a yield of 140 bushels per acre and a nitrogen removal rate of 150 lb/acre (Robert Anderson, Pennsylvania State Extension Service, written commun., 1989). Tobacco and rye removed about 200 lb per acre and 100 lb per acre of nitrogen, respectively (Robert Anderson, Pennsylvania State Extension Service, written commun., 1989). All these sources amounted to a net output of 12,000 lb of nitrogen for the study period.

The amount of nitrogen entering and leaving the system through the soil and by atmospheric processes is unknown. Only soluble nitrate in the top 4 ft of soil was measured, which often represents much less than 10 percent of the total soil nitrogen (Stevenson, 1982). Although alfalfa usually fixes nitrogen from the atmosphere, a process which results in a net increase of nitrogen to a site, alfalfa grown in nitrogen-rich soils may preferentially use soil nitrogen instead of or in addition to atmospheric nitrogen, a process which could potentially result in a net decrease of nitrogen from a site after alfalfa harvesting (Jeff Stoltzfus, Penn State Extension Service, oral commun., July, 1990). For the purpose of the Field-Site 1 nitrogen budget, alfalfa was estimated to obtain approximately 25 percent of its nitrogen requirement from the nitrogen-rich soils, and therefore was considered to be neither an input nor an output in the net nitrogen balance at the site.

The magnitude of error in the nitrogen budget is unknown; however, probable error estimates were made where possible based on observations of site conditions. Applications of manure to the site were

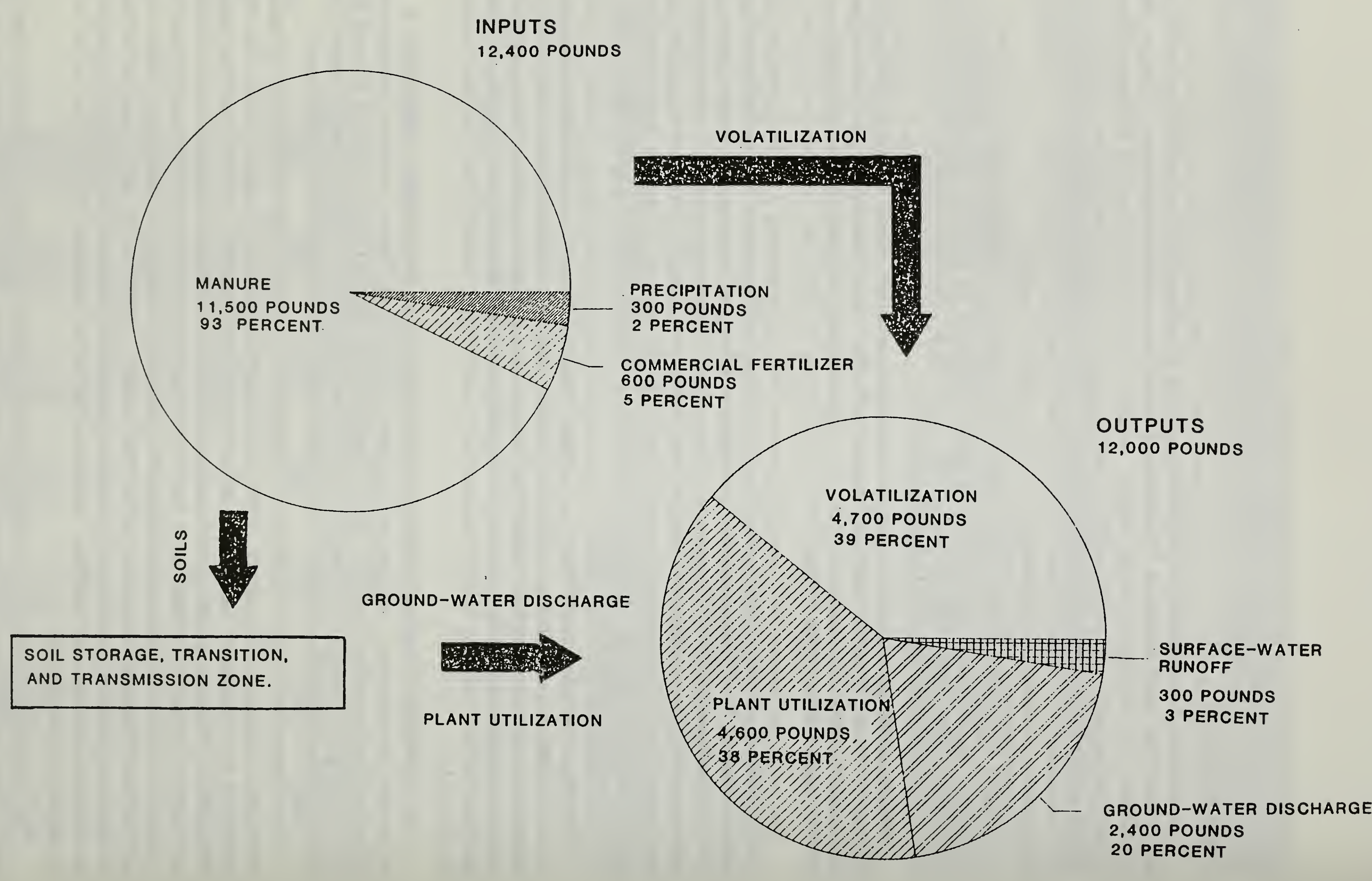


Figure 7.4-51.-- Estimated inputs and outputs of nitrogen at Field-Site 1, from January 1983 through September 1984 (all numbers rounded).

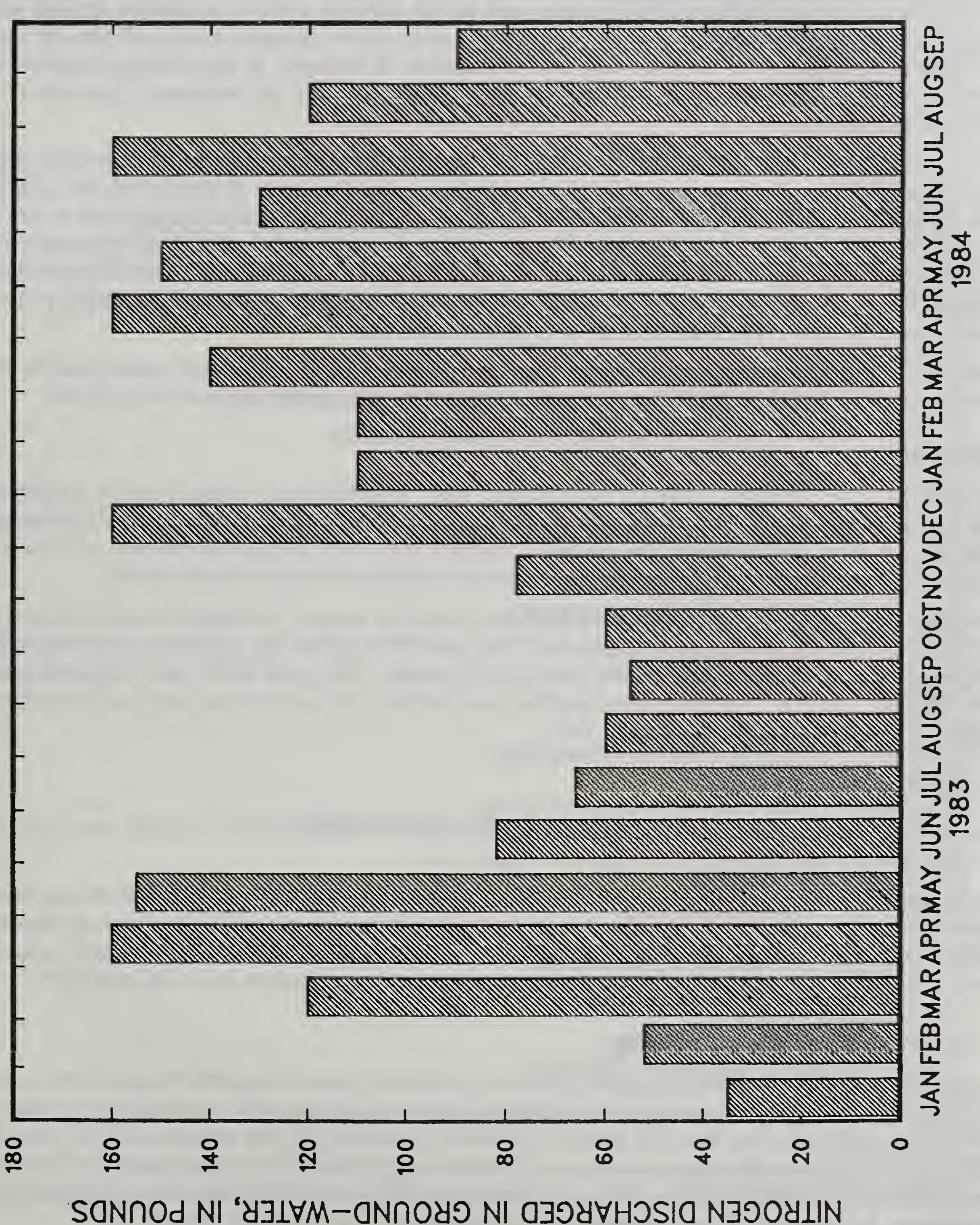


Figure 7.4-52.--Estimated monthly nitrogen loads leaving the site in ground water.

reported in spreader loads by the farmer, and there is an unknown amount of error in the reported values. Manure samples analyzed for nitrogen content were probably not representative of all the manure applied during a year, therefore some error was involved in the calculation of manure loads needed to supply crop nitrogen needs. The nitrogen content of manure varies with moisture content, animal feed type, and animal health and age. Laboratory analysis may also introduce some error. Analyses of dairy manure samples collected from the site ranged from 8.8 lb of nitrogen per ton of manure to 13.8 lb of nitrogen per ton of manure. Differences between the estimated and actual nitrogen content of manure applied to the site could have potentially caused an error in the input side of the nitrogen budget of plus or minus 2,500 lb of nitrogen. Errors in the reporting and calculation of nitrogen in commercial fertilizer and precipitation were probably insignificant because they comprised only an estimated 5 percent of the nitrogen input to the site.

Volatilization rates were roughly estimated for the site during the study period. A 20 percent plus or minus difference in overall nitrogen volatilization could have caused an error of plus or minus 1,000 lb of nitrogen output from the site. A 20 percent error in crop usage of nitrogen could have caused an error of plus or minus 1,000 lb of nitrogen output from the site. Although errors in the estimation of nitrogen loads in surface runoff probably were insignificant because runoff outputs were small, a possible 30 percent error in the calculation of nitrogen discharged in ground water could be significant and could potentially involve an error of plus or minus 750 lb of nitrogen discharged from the site.

The amount of nitrogen stored in the soils, which undoubtedly changes from year to year, may be small compared to possible budget errors. Therefore, soil storage cannot be calculated from the budget.

7.5 FIELD-SITE 2

The 47.5 acre site, which is underlain by carbonate rock, is agricultural cropland and is located near Ephrata in Lancaster County, Pennsylvania (fig. 6-7). The silt loam soils are typically up to 72 inches deep and are moderately to well drained. The site has a median slope of 5 percent (see Section 6.10 for a full description).

Twenty-seven acres of the site are pipe-outlet terraces. Runoff as pipe discharge from the terraces was monitored from October 1984 through September 1986 (pre-BMP) before the nutrient management BMP was implemented, and from October 1986 through September 1988 (post-BMP) after implementation. Ground water at Field-Site 2 was monitored for the same period, but post-BMP monitoring was extended to include October 1986 through September 1990.

7.5.1 Field-Site 2 Precipitation

A recording precipitation gage was installed at Field-Site 2 in October 1984. Monthly precipitation at the site for the study period (1985-90) is shown in figure 7.5-1.

The long-term average precipitation for Field-Site 2 is approximately 43.5 inches based on record from the NOAA precipitation station at Ephrata, Pennsylvania. A comparison of annual precipitation measured at Field-Site 2, long-term annual average precipitation from the Ephrata NOAA station, and percent of measured precipitation deviation from long-term average annual precipitation is shown in table 7.5-1.

7.5.2 Field-Site 2 Agricultural Activities

Significant agricultural-activity changes occurred at Field-Site 2 from the pre-BMP to post-BMP period. The implementation of nutrient management resulted in a reduction of about 45 percent in the nitrogen and phosphorus applied to the site from the pre-BMP (1985-86) period to the first two years of the post-BMP (1987-88) when surface runoff was monitored, and a reduction of 22 percent in the nitrogen and 29 percent in the phosphorus from the pre-BMP period to the entire post-BMP period (1987-90) when the ground water was monitored. A change in tillage practices also occurred during the post-BMP period.

Prior to the implementation of nutrient management at the site, all animal wastes generated from the animal operations were disposed of on the 47.5 cropped acres. Approximately 100 steers, 1,500 hogs (three sets of 500), and 110,000 chickens (five sets of 22,000) were raised at the site each year. In addition to the large

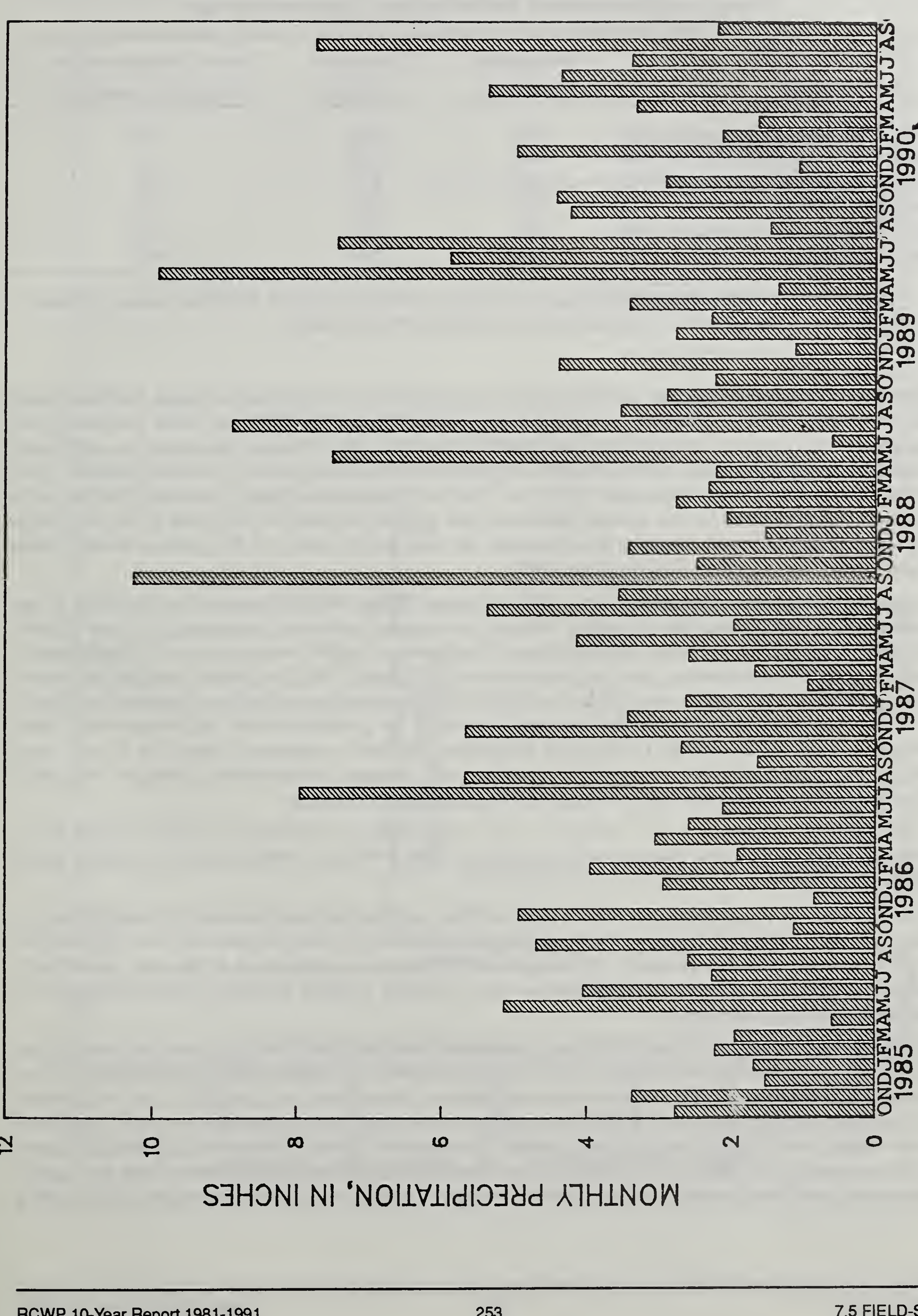


Figure 7.5-1.--Monthly precipitation at Field Site 2

Table 7.5-1.--Comparison of annual precipitation at Field-Site 2, long-term average for Ephrata, Pennsylvania and percent deviation from long-term average

Period	Precipitation, in inches	Long-term average[1]	Percent deviation from long-term average
October 1984 through September 1985	35.8	43.5	-18
October 1985 through September 1986	38.8	43.5	-11
October 1986 through September 1987	45.0	43.5	+03
October 1987 through September 1988	40.4	43.5	-07
October 1988 through September 1989	46.6	43.5	+07
October 1989 through September 1990	43.6	43.5	+00

[1] Long-term average precipitation based on 30 years (1951-80) of record from the National Oceanic and Atmospheric Administration weather station at Ephrata, Pennsylvania.

applications of manure during the pre-BMP period, applications of commercial nitrogen fertilizers were sometimes made as well. However, in recent years, research from Pennsylvania State University has demonstrated that manure nitrogen alone can be sufficient to meet crop nitrogen requirements, and that no increase in crop yield is gained when nitrogen is applied in excess of crop needs (Fox and Piekielek, 1983; Fox and others, 1989). Approximately twice the amount of manure-nitrogen recommended for crop production was generated by the animal operations and typically applied to the fields at the site. These excess applications allowed nitrogen to accumulate in soils and to leach to the ground-water system (Graves, 1986a; Graves, 1986b; Roth and Fox, 1990).

Nutrient management planning (Graves, 1986a; Graves, 1986b), the BMP selected for Field-Site 2, was implemented in 1987. Quantities of applied nitrogen to cropped land were determined by crop nutrient needs rather than animal operation manure-disposal needs when nutrient management was implemented. Because a nutrient-management plan was implemented in October 1986, the farmer exported all animal manure generated at the site in excess of that containing nitrogen amounts needed for maximum crop yield. The nutrient-management plan for the site was developed by personnel from the Pennsylvania State University College of Agronomy Cooperative Extension. Nutrient-management plans for the site were based on crop yield goals, manure application method, soil nitrogen concentrations, nitrogen analysis of manure samples collected at the site, and past manure-application practices.

The nutrient contents of the manures were established by laboratory analysis (table 7.5-2). Representative samples of the manures were collected in 1985, 1987, and 1988, at the time of major spring or fall field applications.

The nitrogen and phosphorus load from each fertilizer application was calculated by multiplying the average nutrient content of the manure(s) or commercial fertilizer by the application amount. Figures 7.5-2 and 7.5-3 show the monthly amounts, of nitrogen and phosphorus applications to the site, respectively. Monthly nitrogen and phosphorus applications were summed to yield the total annual nitrogen and phosphorus loading (table 7.5-3).

In the spring of 1989, Penn State University announced that the "quick" nitrogen soil test which it has had under development for several years would be made available on a limited basis to the public. This test measures the amount of soluble nitrate-nitrogen available in the soil and was designed to be used at side-dress time (early June) to determine if additional nitrogen was necessary for optimum corn yield. Penn State recommended that the test be used on fields which have recently received manure or following a legume crop. Recommended nitrogen side dressing rates were based on soil nitrate test results and corn yield goals. For example, a soil test level of 20 ppm of nitrate nitrogen would result in a recommended side dressing

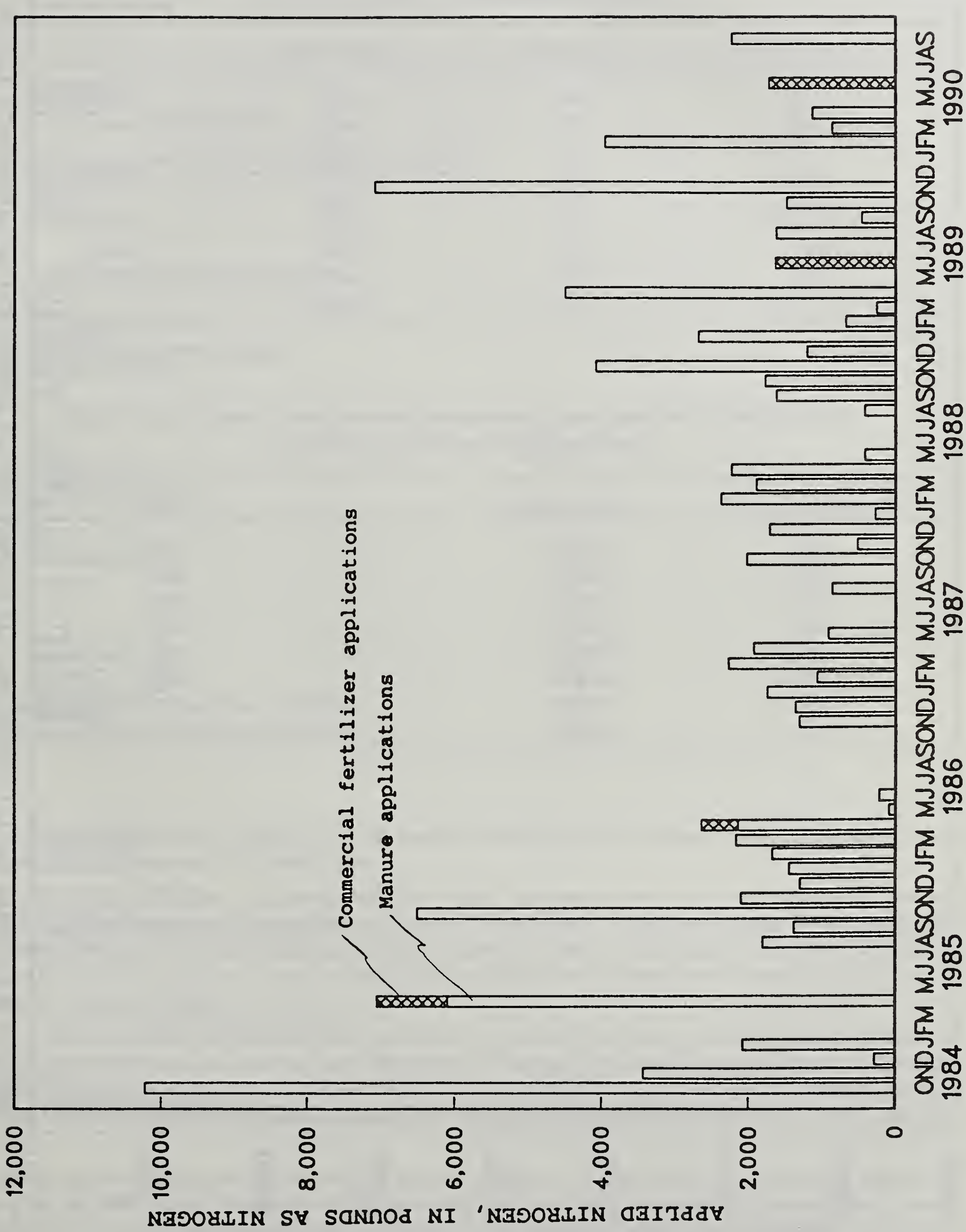


Figure 7.5-2.--Monthly manure and commercial fertilizer nitrogen applications to Field Site 2.

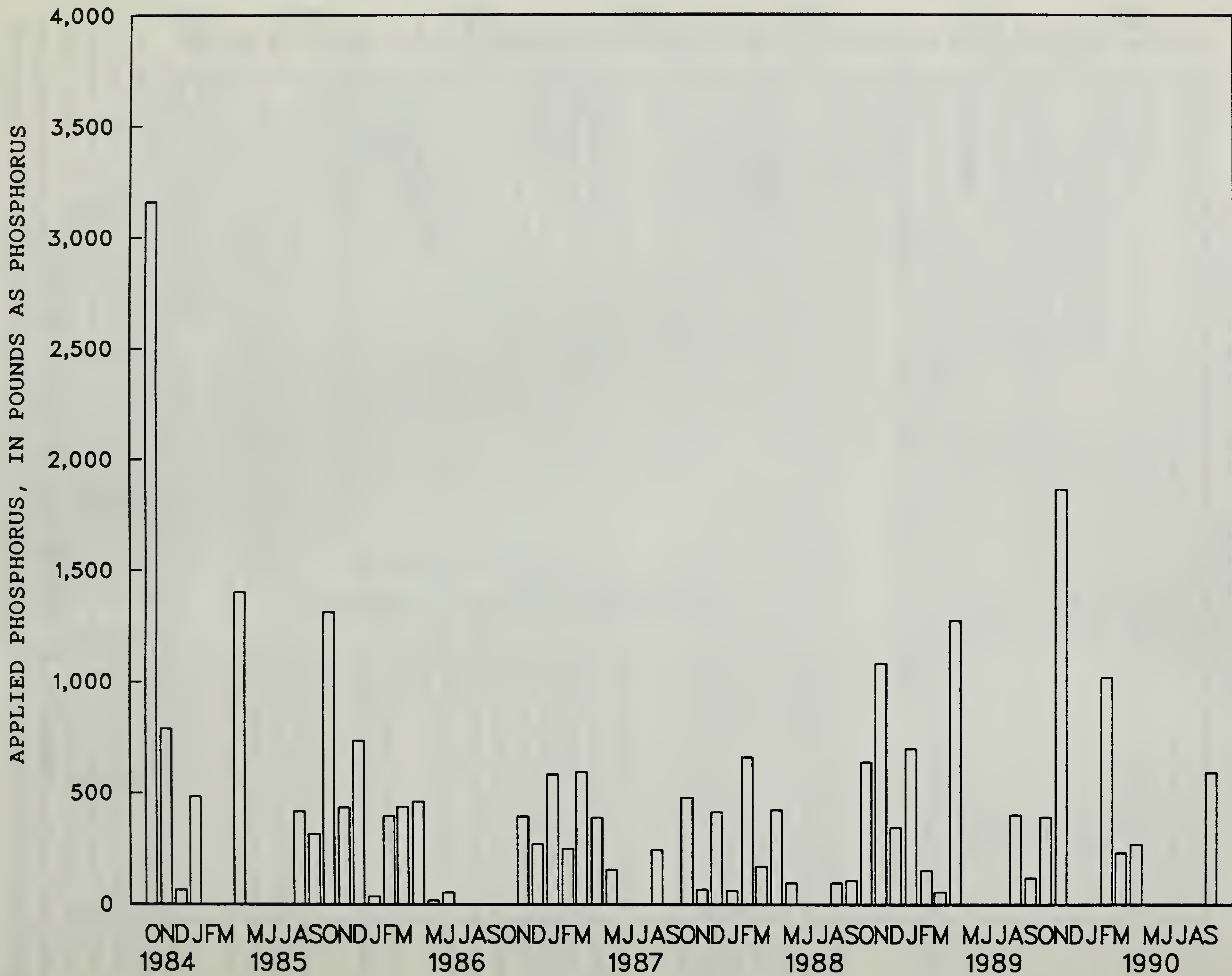


Figure 7.5-3.--Monthly manure phosphorus applications to Field Site 2.

Table 7.5-2.--Average nitrogen and phosphorus content of manure samples collected in 1985, 1987, and 1988, in pounds per ton

Year	Manure type	Nitrogen	Phosphorus
1985	Hog	9.2	2.1
	Steer	19	4.4
	Poultry	66	26
1987	Hog	7.9	1.6
	Steer	19	4.4
	Poultry	65	26
1988	Hog	6.6	.98
	Steer	14	3.2
	Poultry	51	34

Table 7.5-3.--Annual nitrogen and phosphorus loads applied to Field-Site 2, in pounds as nitrogen or phosphorus

Year	Nitrogen load	Phosphorus load
1985	26,400	6,600
1986	19,000	3,700
1987	11,500	2,900
1988	13,500	2,600
1989	18,850	4,800
1990	17,200	4,400
Average annual pre-BMP load (1985-86)	22,700	5,150
Average annual post-BMP load (1987-90)	17,740	3,675

rate of 25 pounds/acre for a yield goal of 100 bushels/acre but the recommended rate for a yield goal of 200 bushels/acre would be 100 pounds/acre.

The owner of Field-Site 2 requested that the "quick" nitrogen soil test be used on his farm. The test showed that some sections of the field site had nitrate levels below 25 parts per million. These areas were side dressed with UAN (urea-ammonium-nitrate) on June 26, 1989, at the recommended rate (either 50 or 75 pounds of actual N per acre). Approximately 29 acres of the field site that were planted in field corn had additional nitrogen applied.

Penn State Cooperative Extension had a test plot on the field site during the 1989 growing season to gather corn yield information and to study the effects of nitrogen side dressing on crop yield. The results are given in table 7.5-4. Additional nitrogen resulted in no statistically measurable yield difference. The test plot was in an area which did not require additional nitrogen based on the results of the "quick" nitrogen soil test.

Tillage practices employed at the site are shown in table 7.5-5. Two tillage practices were employed during the pre-BMP period. Minimum-tillage practices were used on approximately 18 acres having low or no slopes. On higher-slope areas of the site, including the pipe-drained terraces, no-till practices were used. The minimum-till methods consisted of chisel plowing and disking before spring planting. No-till methods, practiced on the remaining acreage including the 27 terraced acres, involved no direct tillage of the soil.

Table 7.5-4.--Results from nitrogen test plot at Field-Site 2 for the 1989 growing season

Additional nitrogen (lb N/acre)	Population (plants/acre)	Yield (bushels/acre)
0	20,375	161
50	19,875	158
75	20,875	154
100	19,875	161

Table 7.5-5--Tillage practices used at Field-Site 2

Year	Tillage
1985	No till - on 29.5 acres
	Minimum till - on 18 acres: chisel plowed[1] throughout nongrowing season and disked before spring planting
1986	No till - on 29.5 acres
	Minimum till - on 18 acres: chisel plowed throughout nongrowing season and disked before spring planting
1987	Minimum till - chisel plowed throughout nongrowing season, disked before spring planting
1988	Minimum till - approximately 15 acres moldboard plowed in spring, entire site chisel plowed throughout year and disked in spring
1989	Minimum till - approximately 15 acres moldboard plowed in winter, entire site chisel plowed throughout year and disked in spring
1990	Conventional till - entire site moldboard plowed in spring, entire site chisel plowed throughout year and disked in spring

[1] Hog manure injection causes soil tillage that is essentially identical to chisel plowing. Hog manure is injected throughout the nongrowing season.

Rather, the soil was kept under continuous crop cover which permitted natural processes to maximize infiltration and minimize erosion. A winter cover crop of rye was planted after harvest and remained on the field until spring planting. The rye was then sprayed with herbicide and corn was planted through the rye residue. No-till practices, used on 29.5 acres, were changed to minimum till in the post-BMP period. Minimum-till practices on the remaining 20.5 acres were continued from the pre-BMP through most of the post-BMP period. In 1988 and 1989, approximately 15 acres along the eastern border of the site were moldboard plowed, and in 1990 the entire site was moldboard plowed in order to alleviate soil compaction problems. Additionally, winter cover crops were used during the pre-, but not the post-BMP period, and cropping patterns changed, although corn and tobacco remained the predominant crops throughout the study.

Tillage practices and water quantity and quality are related primarily by the effect the former has on infiltration and erosion. The processes by which tillage affects infiltration and erosion, although thoroughly investigated, are not easily quantified (Baker, 1987). During the pre-BMP period, the 27 acre surface-runoff drainage basin was cultivated almost exclusively in no-till; therefore, tillage induced variations in surface-

water quantity and quality were expected to be minimal. However, the pre-BMP to post-BMP changes in tillage were great and may have substantially affected hydrologic conditions at the site.

Fertilization at the site was accomplished using both manure and commercial fertilizer. The manure was of three types: hog manure from gestation and finishing operations, steer manure and bedding mixture from a feedlot, and poultry manure from a poultry house. The steer-manure mix and the poultry manure were applied by surface spreading. The gestating and finishing hog manure was injected into the soil 8-10 in. below the surface unless the soil was frozen. In the case of frozen soil, all manures were surface spread. The commercial fertilizers applied were ammonium sulfate, broadcast prior to planting, and a nitrogen liquid coapplied with pre-emergent pesticides.

Planting and harvesting were scheduled by growth requirements of the crops and prevailing field conditions. Corn, the primary crop, was usually planted during the last 2 weeks in April and harvested from mid- to late-September. Tobacco, which requires a shorter, warmer season, was transplanted from starting beds to the field in mid-June and harvested in mid- to late-August. During 1985 and 1986, a winter cover crop of rye was broadcast seeded after corn harvesting and covered primarily the pipe-drained terraces. The rye was not harvested but was sprayed with herbicide prior to the planting of corn. In 1987, a winter cover crop of sudan grass was planted on 5.5 acres of the site. Beginning in 1988 fruit and vegetables, in addition to sweet corn, were cultivated. In 1989 and 1990 more acreage was planted in fruit and vegetables than in tobacco. Crop acreage for the years 1985-90 are listed in table 7.5-6.

Crops potentially influence surface-water and ground-water quantity and quality through processes such as interception of precipitation, transpiration, and uptake of water and nutrients. Interception of precipitation by crop foliage reduces the kinetic energy of precipitation, and subsequently reduces the ability of precipitation to seal the surface against infiltration and to dislodge sediment and nutrient bearing materials on or in the soil. These conditions can continue after harvest if sufficient crop residue remains. As a result, the sediment and nutrient concentrations in surface-water runoff may be different from concentrations under similar conditions without crops. At the same time, infiltration of precipitation and nutrients is characteristically increased because of reduced impact consolidation (Musgrave and Holtan, 1964). Additionally, during periods of active growth, crops take up a substantial amount of soil water and nutrients, in turn reducing the amount available for ground-water recharge.

Table 7.5-6.--Annual crop acreage at Field-Site 2

Year	Growing season	Crop type	Acreage
1985	Summer	Corn	43.5
	Summer	Tobacco	4.0
	Winter (1984-85)	Rye	22.5
1986	Summer	Corn	43.5
	Summer	Tobacco	4.0
	Winter (1985-86)	Rye	25.0
1987	Summer	Corn	42
	Summer	Tobacco	5.5
	Winter (1986-87)	Sudan grass	5.5
1988	Summer	Corn	39.5
	Summer	Tobacco	5.0
	Summer	Fruit and vegetables	2.5
1989	Summer	Corn	35
	Summer	Tobacco	2.5
	Summer	Fruit and vegetables	10
1990	Summer	Corn	37
	Summer	Tobacco	4.0
	Summer	Fruit and vegetables	6.5

7.5.3 Field-Site 2 Soils

Table 7.5-7 contains a summary of soluble nitrate-nitrogen and soluble phosphorus results from soil sampling conducted at Field-Site 2. Except for one sampling period, the mean-nitrate concentrations exceeded the maximum recommendation of 100 pounds/acre in the top four feet of the soil profile, yet nitrate concentrations in ground-water samples typically exceeded 10 mg/L nitrate as nitrogen. Baker (1986) has theorized that if a typical silt loam contains no more than 50 pounds/acre of soluble nitrate nitrogen evenly distributed throughout the upper four feet, water moving under the force of gravity should not contain more than 10 mg/L of nitrate nitrogen. However, because of the large variability in soil nitrate concentrations and the uneven distribution of nitrate in the soil profile, soil concentrations of up to 100 pounds/acre may be acceptable and not cause ground-water concentrations of nitrate to exceed 10 mg/L (Simons, 1991).

Soluble nitrate and soluble phosphorus concentrations in soil samples frequently ranged over three orders of magnitude during a single sampling period. Although such variation could be expected at a farm where different fields and crops received substantially different loading of fertilizers, data collected at Field-Site 2 indicate that soil samples collected just several feet away from one another in the same field also showed variance of up to three orders of magnitude of variation in soluble nitrogen and phosphorus concentrations. The large amount of variance in the soil data made the detection of any trends present in the data impossible.

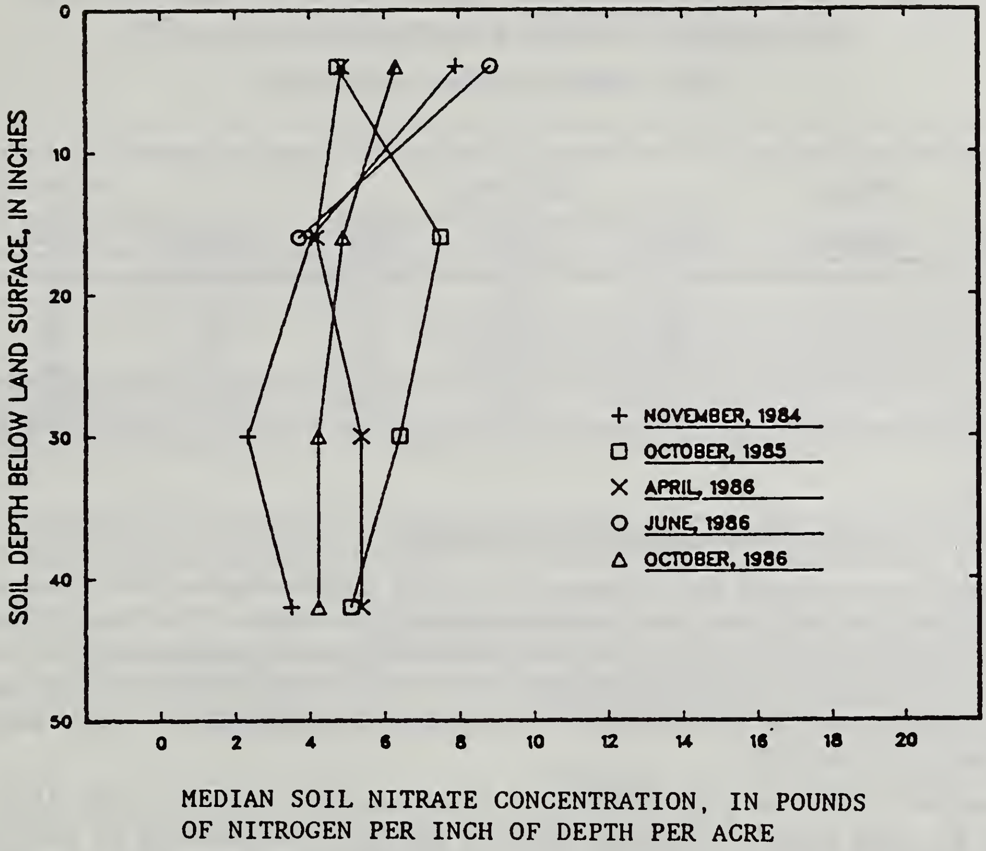
A profile of the median soil-nitrate and soluble phosphorus concentrations by depth for the period 1984-86 is shown in figure 7.5-4 Although there was considerable variation in the nitrate concentrations of individual samples in any specific depth segment, median nitrate concentrations showed, on the average, a gradual decrease with increasing depth. The only substantial departure from this pattern occurred in the October 1985 sampling when the 8- to 24-in.-depth nitrate concentrations exceeded the 0- to 8-in.-depth concentrations. Seven days prior to this sampling, 2,800 lb of manure nitrogen were injected to a depth of 8- to 10-in. Median soil-phosphorus concentrations were near or below detection limits for all but the 0-8 in.-depth segment. Binding of the phosphorus with soil particles near the surface prevented orthophosphorus movement beyond the 0- to 8-in. depth.

Soil samples were collected to depths of 8 feet during spring and fall of 1989 and 1990 (table 7.5-8). Analyses indicate that substantial amounts of soluble soil-nitrogen leach below the crop root zone.

Table 7.5-7.--Soluble nitrate-nitrogen and soluble phosphorus content in the top 4 feet of the soil profile at Field-Site 2 (in pounds/acre as N and P)

[Min, minimum; Max, maximum]

Sampling date	No. of samples	Soluble NO_3-N			Soluble P		
		Mean	Min	Max	Mean	Min	Max
Fall 1984	2	224	177	272	6.1	3.9	7.8
Fall 1985	11	265	128	428	28	3.5	160
Spring 1986	14	291	77	614	33	4.4	77
Fall 1986	9	227	104	364	27	2.6	45
Spring 1987	9	123	85	184	35	6.5	110
Fall 1987	9	96	31	180	22	1.3	63
Spring 1988	9	147	68	222	22	5.2	42
Fall 1988	9	205	46	462	17	4.8	52
Spring 1989	5	260	150	389	16	2.2	36
Fall 1989	5	182	110	251	27	3.9	57
Spring 1990	5	186	126	262	25	1.7	45
Fall 1990	5	170	80	324	24	4.4	47



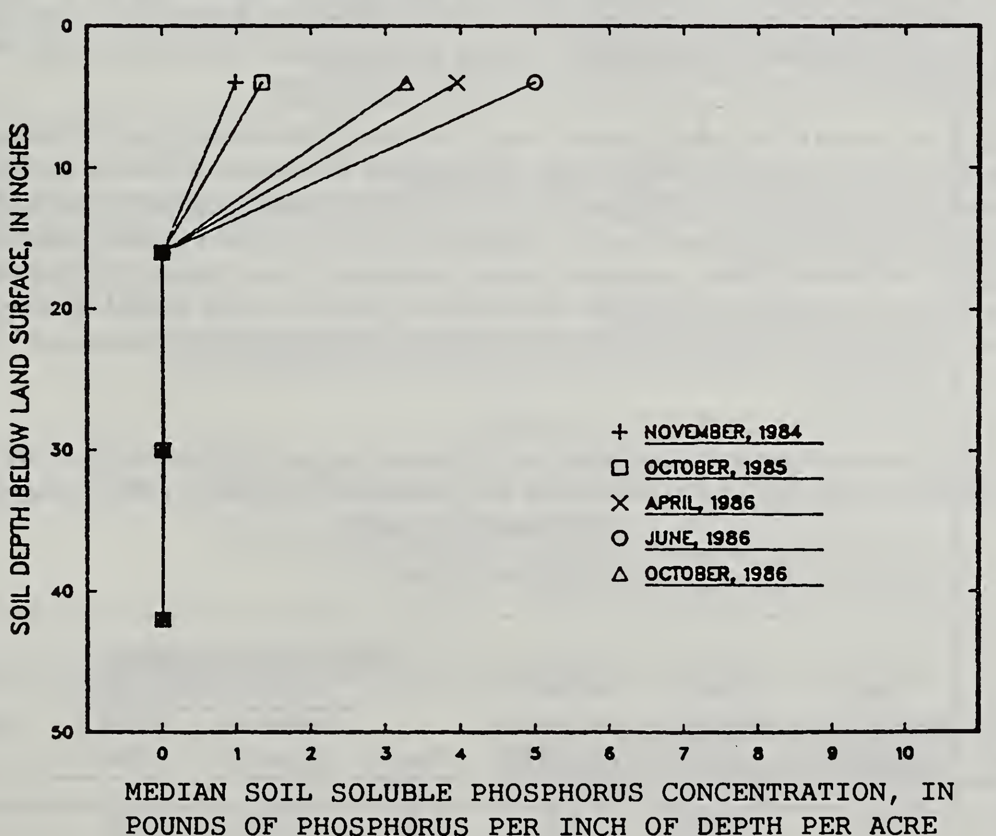


Figure 7.5-4.--Median soil nitrate-nitrogen concentrations (above) and soluble phosphorus concentrations (below).

Table 7.5-8.--Soluble nitrate-nitrogen content in the top 8 feet of the soil profile at Field-Site 2 (in pounds per acre as N)

[Min, minimum; Max, maximum]

Sampling date	No. of samples	0 to 4 feet Mean	0 to 4 feet Min	0 to 4 feet Max	4 to 8 feet Mean	4 to 8 feet Min	4 to 8 feet Max
Spring 1989	4	228	150	302	136	82	164
Fall 1989	4	200	130	251	251	85	499
Spring 1990	4	194	126	262	175	99	263
Fall 1990	4	194	80	324	201	134	277

7.5.4 Field-Site 2 Surface-Runoff Quantity And Quality

Surface runoff was monitored for two years prior to BMP implementation, from October 1984 through September 1986, and for two years after implementation, from October 1986 through September 1988. Water-quality samples of pipe discharge were collected during 22 of 36 runoff events in the pre-BMP period and during 26 of 38 runoff events during the post-BMP period. Samples from all of the sampled runoff events were analyzed for total nutrients, and samples from 12 pre-BMP and 9 post-BMP events were analyzed for suspended sediment.

Annual discharge from the pipe draining 27 terraced acres is listed in table 7.5-9. Total annual discharges for the study period varied from 28,800 to 130,000 ft^3, representing 0.7 to 3.3 percent of the precipitation. Monthly discharges for the study period are shown in figure 7.5-5. The highest monthly discharges generally occurred in the winter during frozen-ground conditions, and during summer thunderstorm periods.

During the first 3 years of the study greater than 75 percent of the annual pipe discharge resulted from 5 or less of storm events. In the 1985 water year, 79 percent of the annual discharge occurred during one storm, on February 12-13, a storm during which 0.87 in. of precipitation occurred during frozen soil and snowcover conditions. In the 1986 water year, a combination of five storms in January and February which occurred when the soils were frozen and snow covered accounted for 46 percent of the annual discharge, and one thunderstorm on July 26 accounted for another 42 percent of the annual discharge. In the 1987 water year, two summer storms, on September 8 and July 1 accounted for 40 percent and 22 percent of the

Table 7.5-9.--Estimated annual runoff data for 27 terraced acres at Field-Site 2 for the pre-BMP (October 1984 through September 1986) and the post-BMP (October 1986 through September 1988) study periods

[ft^3, cubic feet]

BMP	Water year	Total precipitation (inches)	Total discharge (ft^3)	Percent of precipitation that ranoff	Total annual nitrogen load: Pounds	Median percentage[1]: Ammonia + organic N	Median percentage[1]: Nitrite + nitrate	Total annual phosphorus load, in pounds
Pre	1985	36	60,900	1.7	62	58	42	28
Pre	1986	39	29,800	.8	25	47	56	9.1
Post	1987	45	28,800	.7	14	43	57	8.4
Post	1988	40	129,700	3.3	93	66	31	44

[1] Median of measured storms only.

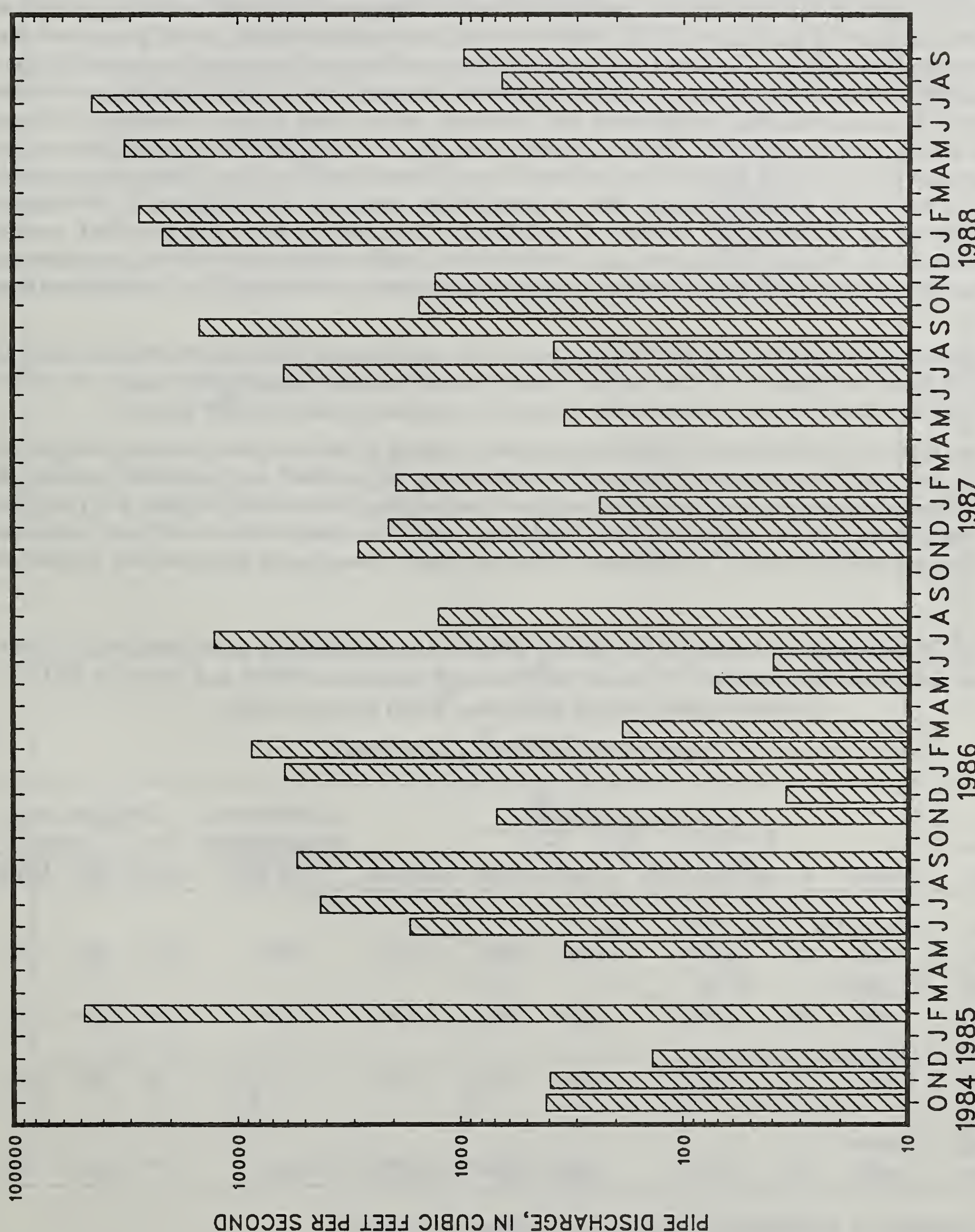


Figure 7.5-5.-- Monthly pipe discharge from 27 terraced acres at Field Site 2.

annual discharge, respectively. Discharge from three storms in December and January when soils were frozen accounted for an additional 14 percent of the annual discharge.

In the 1988 water year, the discharge was more evenly distributed between storms. One storm on May 19 accounted for 17 percent of the annual discharge, and four storms in July contributed an additional 31 percent of the annual discharge. Eight storms during frozen ground conditions in January and February accounted for 38 percent of the annual discharge. During the entire 4-year study period, all storms on frozen ground had less than 1.0 in. of precipitation.

A positive correlation existed between pre-BMP precipitation quantity and the logarithm of total storm discharge. The regression relation between precipitation and discharge was different for thawed and frozen soil conditions (figure 7.5-6 and table 7.5-10). Although based on six storms which generally occurred over snow-covered ground, figure 7.5-6 shows total storm discharge on frozen soil increased exponentially faster than discharge on thawed soil as the precipitation quantities increased. No statistically significant relation was detected between post-BMP precipitation and discharge under frozen ground conditions, although post-BMP data were within the same range as pre-BMP data (fig. 7.5-7 and table 7.5-10). A higher amount of discharge per amount of precipitation was recorded during thawed-soil conditions during the post-BMP period than during the pre-BMP period. But, as precipitation increased, the difference in the relation between amount of discharge and amount of precipitation from the pre-BMP and post-BMP periods decreased (fig. 7.5-8). An analysis of covariance confirmed the significant difference between the slopes and intercepts of the two regression lines, when one unusually large storm contributing 5.0 in. was omitted from the data set.

Additionally, a pre-BMP to post-BMP comparison of the percentage of precipitation that became pipe discharge is shown in figure 7.5-9. The median percent runoff increased significantly (using the Mann-Whitney test) from 0.66 percent in the pre-BMP period to 1.9 percent in the post-BMP period.

Because there was no statistically significant change (according to Mann-Whitney test) in precipitation quantity or intensity of storms which produced runoff during the pre-BMP and post-BMP periods, the change in the relation between total storm discharge and precipitation between the pre-BMP and post-BMP periods was probably due to changes in tillage and crop cover. The change from no-till and continuous cover during the pre-BMP period to minimum till and no winter cover during the post-BMP period was

Table 7.5-10.--Regression statistics for the log of total storm discharge as a function of storm precipitation for the pre-BMP (October 1984 through September 1986) and the post-BMP (October 1986 through September 1988) study periods

[n, number of storms; <, less than]

Dependent variable	Dataset	n	Regression coefficient: Storm precipitation	t-test	p-value	Intercept	Coefficient of determination (Adj. R^2)[1]	Standard error: Log units	Standard error: Percent[2] Plus	Standard error: Percent[2] Minus
Pre-BMP discharge	Thawed soil	23	0.677	7.128	<0.001	1.554	0.69	0.42	163	62
Post-BMP discharge	Thawed soil	26	.560	3.378	.002	2.479	.29	.51	224	69
Pre-BMP discharge	Frozen soil	7	3.337	3.238	.023	1.132	.61	.66	357	78
Pre- and post-BMP discharge	Frozen soil	17	1.719	2.267	.039	2.257	.21	.71	413	80

[1] Coefficient of determination (R^2) adjusted for degrees of freedom.
[2] Presented as described by Tasker (1978).

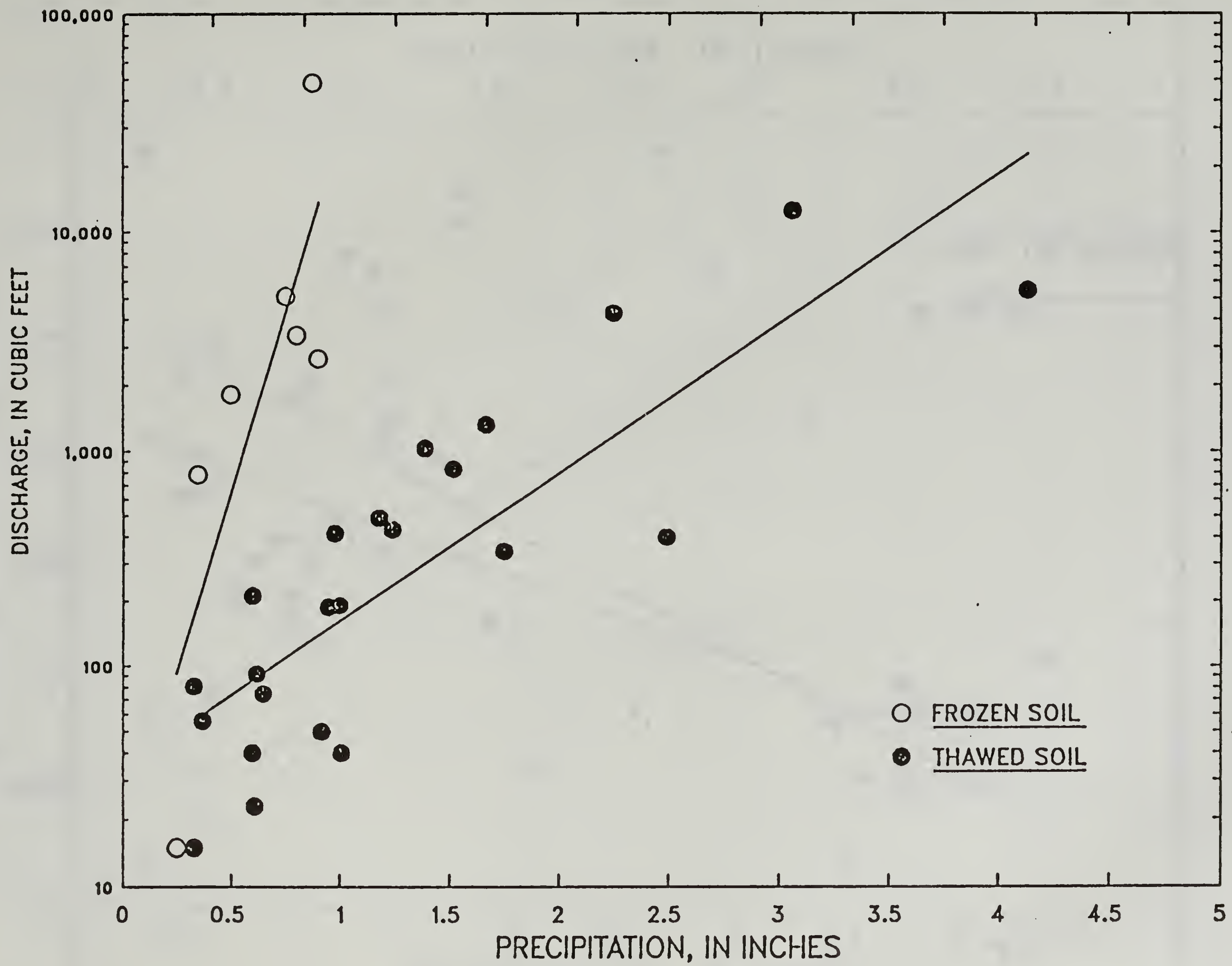


Figure 7.5-6.-- Relation between pipe discharge and precipitation for storms occuring on thawed and frozen soil during the pre-BMP period (1985-1986), excluding discharge from snowmelt only. (Regression line statistics are shown in Table 7.5-10.)

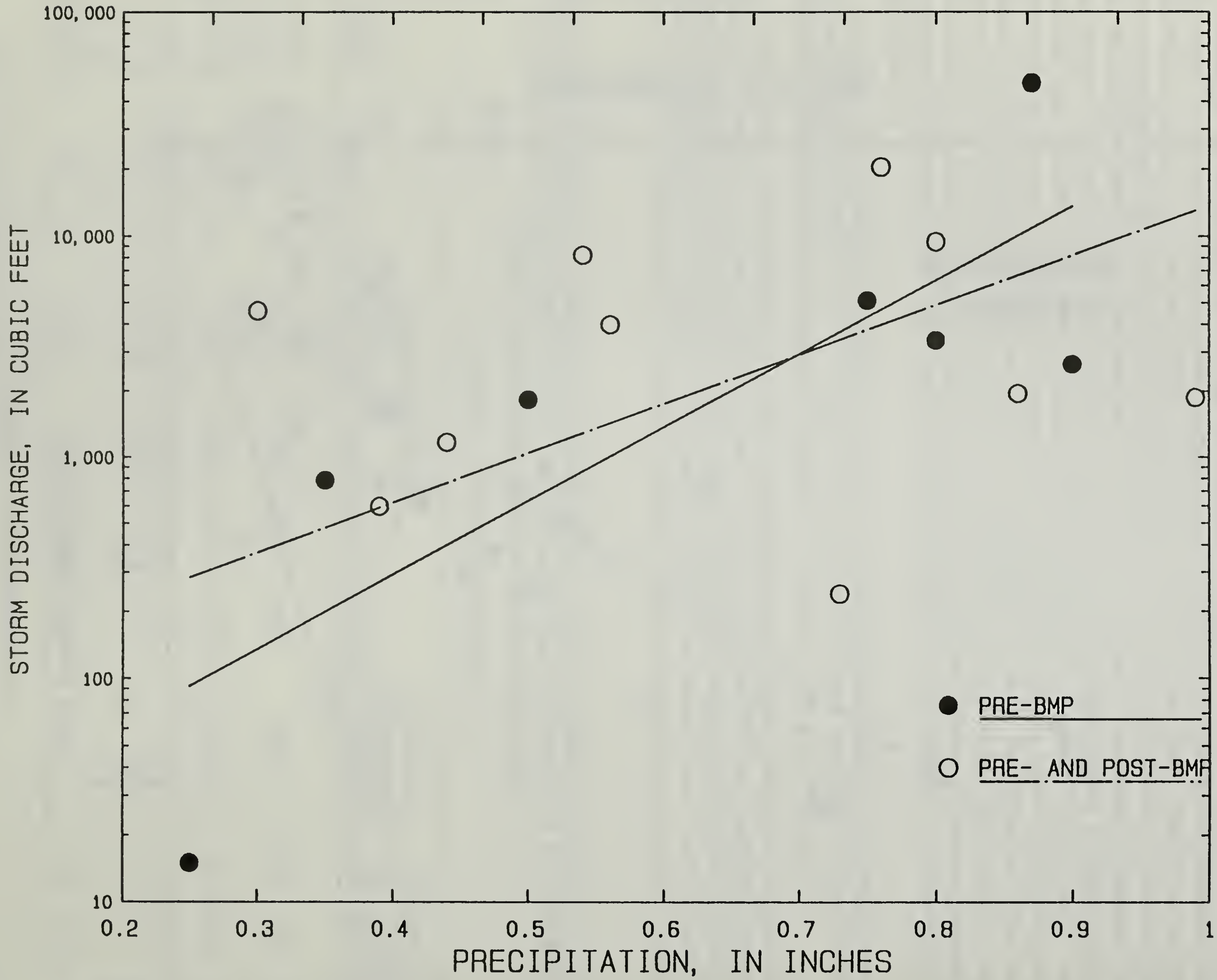


Figure 7.5-7.-- Relation between pipe discharge and precipitation for storms occuring on frozen soil during the pre-BMP (1985-1986) and post-BMP (1987-1988) periods, excluding discharge from snowmelt only (Regression line statistics are shown in Table 7.5-10).

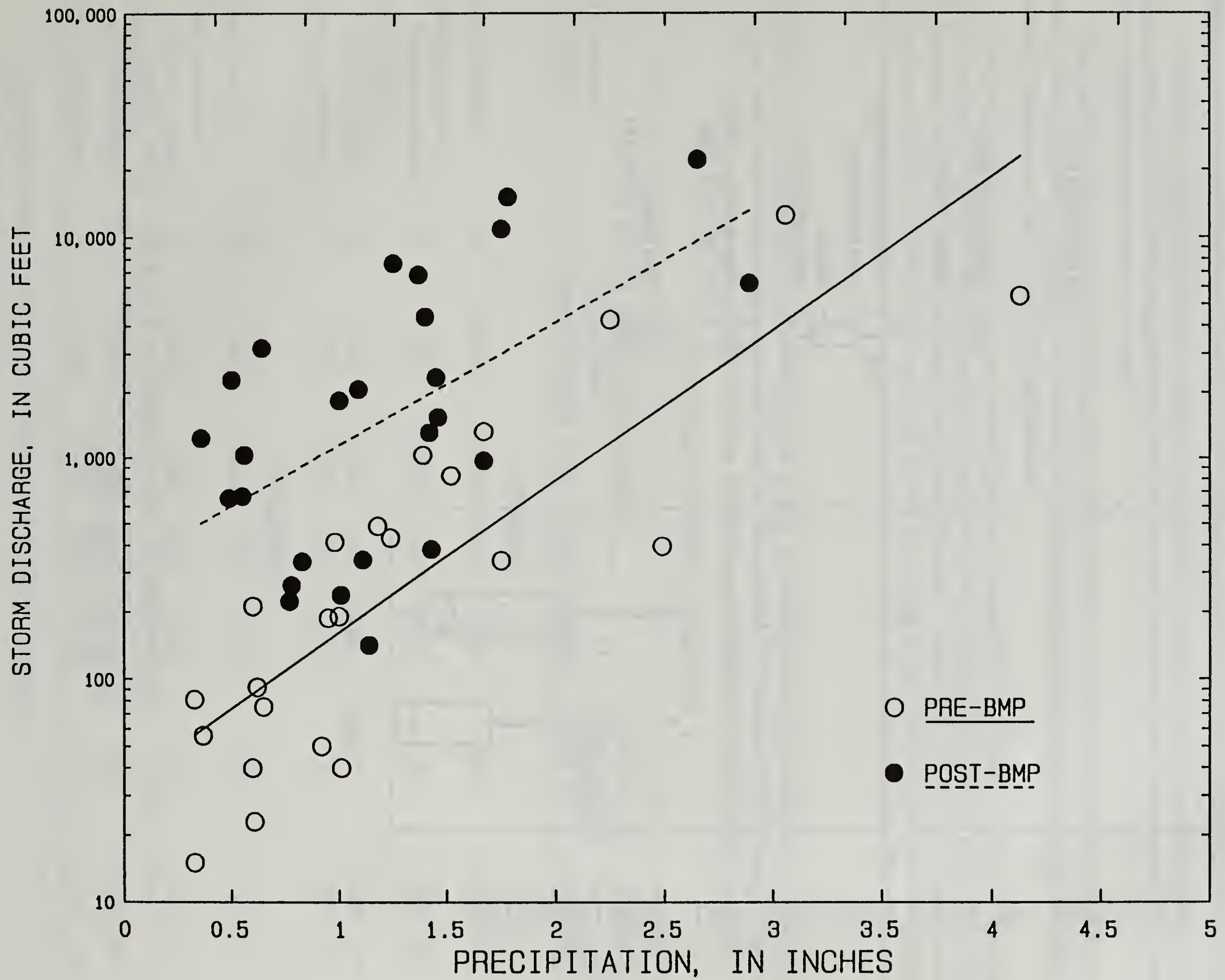


Figure 7.5-8.-- Relation between pipe discharge and precipitation for storms occuring on thawed soil during the pre-BMP (1985-1986) and post-BMP (1987-1988) periods, excluding discharge from snowmelt only (Regression line statistics are shown in Table 7.5-10).

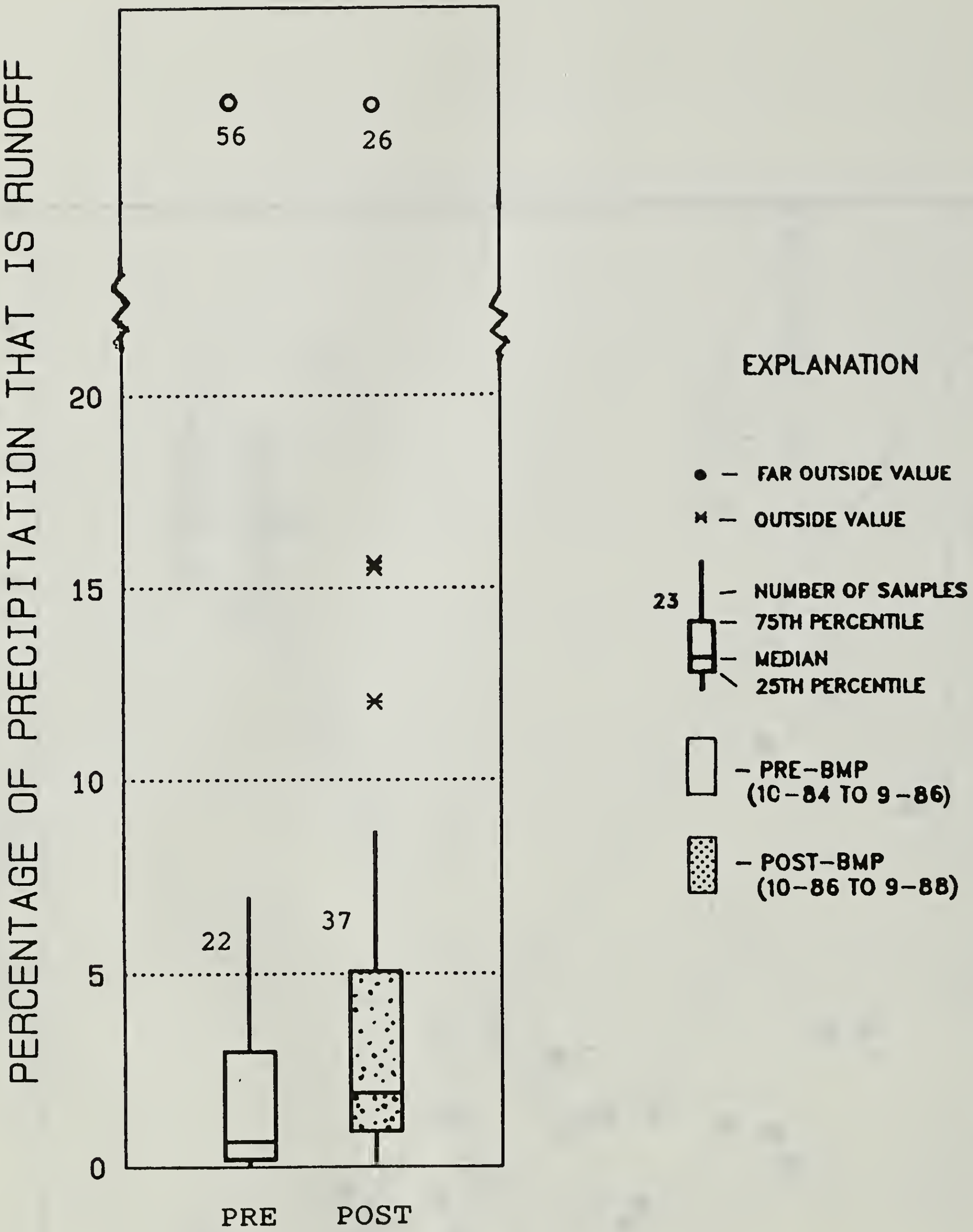


Figure 7.5-9.-- Percentage of precipitation for each storm that was discharged as surface runoff from 27-terraced acres at Field-Site 2.

expected to increase runoff particularly during the nongrowing season. However, under frozen ground conditions reduced infiltration minimized the differences in the pre-BMP and post-BMP period discharge-precipitation relations caused by tillage systems.

Nutrient loads from the pipe discharge of 27 terraced acres are shown in table 7.5-9. Nutrient loads for unsampled storms were estimated using the regression equations for measured storms during the pre-BMP and post-BMP periods (table 7.5-11). For the study period, total nitrogen loads ranged from 15 to 90 pounds, of this, about half was ammonia plus organic nitrogen, and about half nitrate plus nitrite nitrogen. The annual total phosphorus load ranged from 8 to 40 pounds. The annual nutrient loads from the pipe discharge represented less than 2 percent of the nutrients applied to the fields drained by the terraces.

Insufficient suspended-sediment data was collected to estimate annual sediment loads. Nutrient management, the only BMP change implemented for the study at this site, was not expected to substantially affect sediment concentrations or loads.

The results of this study point out that large contributions to the total storm runoff come from storms during frozen-ground conditions, and therefore emphasize the importance of targeting this condition when making decisions on BMPs should be emphasized.

For the pre-BMP period, runoff on frozen ground accounted for 76 percent of the total-nitrogen load and 75 percent of the total-phosphorus load. These loads were carried by 68 percent of the pipe discharge. In February 1985, two storms accounted for 82 and 80 percent, respectively, of the total-nitrogen and total-phosphorus load for the 1985 water year, and 58 and 61 percent of the total-nitrogen and total-phosphorus loads for the study period. These two storms occurred one month after surface applications of manure were

Table 7.5-11.--Regression statistics for the log of nutrient loads, in pounds, as a function of the log of total storm discharge, in cubic feet, for the pre-BMP (October 1984 through September 1986) and the post-BMP (October 1986 through September 1988) study periods

[n, number of storms; <, less than]

Dependent variable	n	Regression coefficient: Log of total storm discharge	Regression coefficient: t-test	Regression coefficient: p-value	Intercept	Coefficient of determination (Adj. R^2)[1]	Standard error: Log units	Standard error: Percent[2] Plus	Standard error: Percent[2] Minus
Pre-BMP									
Total nitrogen	22	0.963	12.248	<0.001	-2.959	0.89	0.260	82	45
Total ammonia + organic nitrogen	22	.957	10.723	<.001	-3.246	.84	.310	104	51
Total nitrate + nitrite nitrogen	22	.832	12.636	<.001	-2.881	.88	.228	69	41
Total phosphorus	22	.951	12.651	<.001	-3.325	.88	.261	82	45
Post-BMP									
Total nitrogen	26	.865	9.364	<.001	-2.719	.78	.281	91	48
Total ammonia + organic nitrogen	26	.819	7.244	<.001	-2.828	.67	.344	121	55
Total nitrate + nitrite nitrogen	26	1.111	4.905	<.001	-4.155	.48	.688	388	79
Total phosphorus	26	.799	10.785	<.001	-2.758	.82	.225	68	40

[1] Coefficient of determination (R^2) adjusted for degrees of freedom.

[2] Presented as described by Tasker (1978).

made on frozen ground with snow cover. Total ammonia plus organic nitrogen accounted for 88 percent of the total-nitrogen load discharge from these storms. By comparison, total ammonia plus organic nitrogen accounted for 31 to 69 percent of the total-nitrogen load in other storms. Forty-four percent of the 1986 nitrogen load and 40 percent of the 1986 phosphorus load was discharged by one January event occurring during frozen-ground conditions 15 days after surface application of manure.

Runoff on frozen ground accounted for 35 percent of the total nitrogen load and 40 percent of the total phosphorus load in pipe discharge during the post-BMP period. These loads were carried by 34 percent of the total post-BMP discharge. Three storms on frozen ground in January and February 1988 made up 35 percent of both the 1988 annual total nitrogen and total phosphorus loads. Although the timing of nutrient applications was about the same for the two periods and overall total nitrogen and phosphorus loads were higher during the post-BMP period, the total amount of nitrogen in pipe discharge during frozen ground conditions decreased in the post-BMP period from 65 to 40 pounds; total phosphorus decreased from 30 to 20 lb. Because frozen ground conditions minimize the tillage practice differences between the pre- and post-BMP periods, his decrease may have been a result of nutrient management which reduced the amount of nutrients applied by about 45 percent from the pre-BMP to the post-BMP period.

During the post-BMP period, large summer storms (greater than 1.0 in. of precipitation) also contributed substantially to the total load. One storm in May 1988, contributing 2.65 in. of rain, discharged 22 percent of the total post-BMP nitrogen load and 14 percent of the total phosphorus load. Two storms in July 1988 contributed another 10 percent of the total nitrogen load, and 8 percent of the total phosphorus load.

The distribution of mean storm concentrations and loads for the pre-BMP and the post-BMP periods are shown in figure 7.5-10 and compared using the Mann-Whitney test. The mean storm nitrate plus nitrite concentrations decreased significantly (95 percent confidence interval) between the pre-BMP and post-BMP periods while other nutrient species remained relatively unchanged. The decrease from a median nitrate plus nitrite concentration of 5.9 to 4.0 mg/L, may have been caused by decreased contact time between surface runoff and highly soluble nitrate in the nutrient-rich soils. However, the change in nitrate concentration was not large enough to change the total nitrogen concentrations significantly. Median total nitrogen and total phosphorus loads increased in the post-BMP period from 1.0 to 1.8 pounds and 0.3 to 0.8 pounds, respectively (fig. 7.5-10). Increases in ammonia plus organic nitrogen accounted for most of the increase in total nitrogen loads. Although the median post-BMP total nitrogen and total phosphorus loads were larger than the pre-BMP loads, analysis of covariance detected no significant change in the nitrogen and phosphorus loads for a storm of a given total discharge (figs. 7.5-11 and 7.5-12). As can be seen in table 7.5-9, the percentage of runoff was much greater in the year when the terraced area was plowed and no winter cover crop was planted. Even though less manure was applied in 1988 than previous years, more nitrogen, phosphorus, and sediment was discharged from the 27 acres because the amount of runoff was greater.

Nutrient management did not appear to have a substantial influence on nutrient concentrations or loads in runoff, except perhaps during frozen ground conditions. Rather, changes in tillage practices and precipitation patterns resulted in the pre-BMP to post-BMP changes in concentrations and loads.

In addition to the increase in nutrient loads during the 1988 water year, the amount of suspended sediment that was discharged also increased due to the lack of a winter cover crop and the change in cultivation methods. These agricultural-activity changes resulted in more soil being available for transport in runoff. During the entire 4-year monitoring period the suspended sediment was generally discharged as silt and clay with very little sand. All except one of the 14 samples analyzed for the silt/clay fraction contained greater than 93 percent silt and clay.

Evaluating any effect that nutrient management has on runoff water quality can be simplified if a quantitative relation between water quality and nutrient applications can be demonstrated. Thus, for runoff data from Field-Site 2 for the pre-BMP period, graphical (figs. 7.5-13 and 7.5-14) and regression methods were used to identify variables that explain the variation in the mean-storm nutrient concentrations (Edward Koerkle and others, U.S. Geological Survey, written commun., 1990). Variables considered included precipitation, 5- and 7-day antecedent precipitation, nutrient applications, and factors affecting

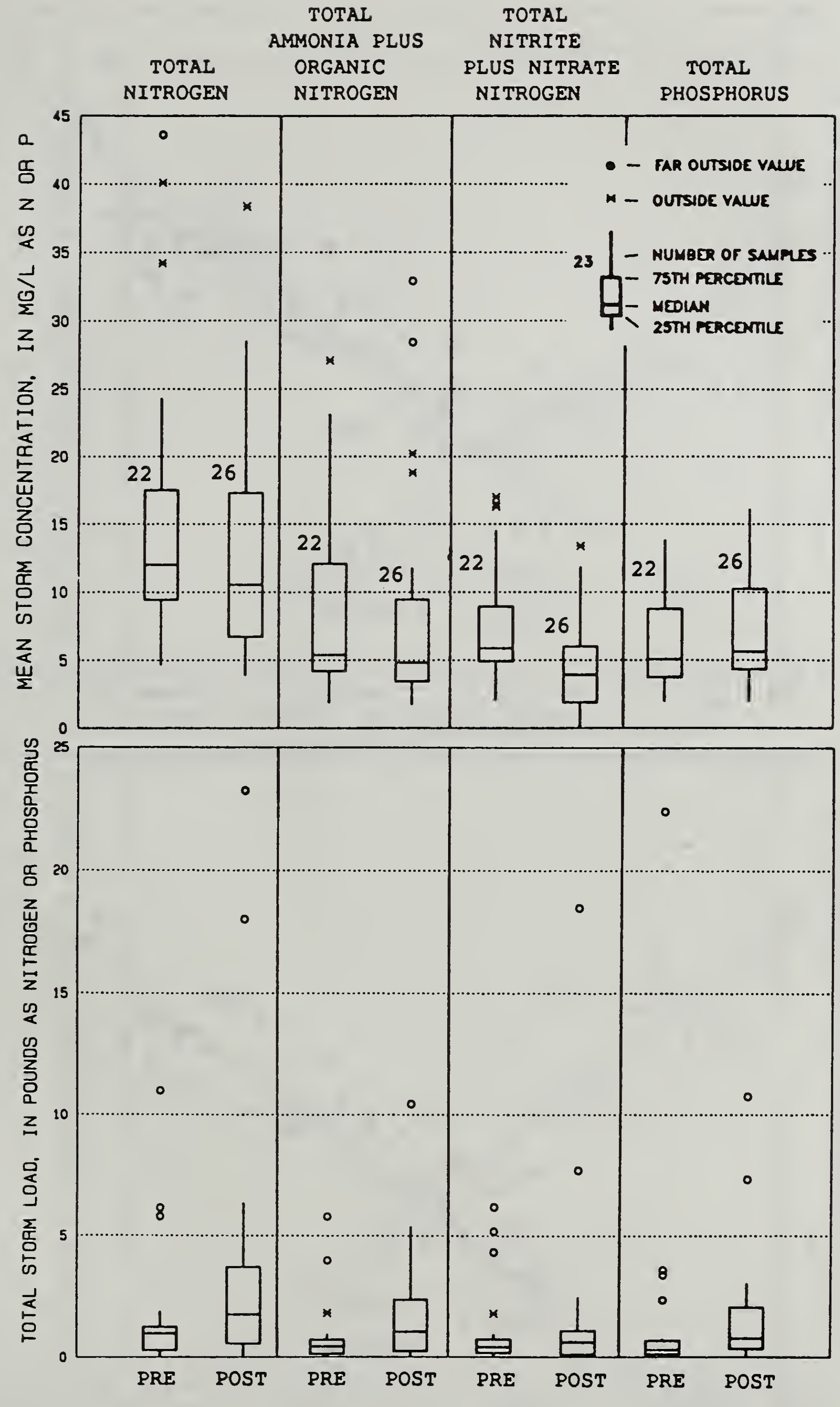


Figure 7.5-10.-- Mean storm concentrations (top) and total storm loads (bottom) of nitrogen and phosphorus for the pre-BMP (October 1984 through September 1986) and the post-BMP (October 1986 through September 1988) study periods at Field-Site 2.

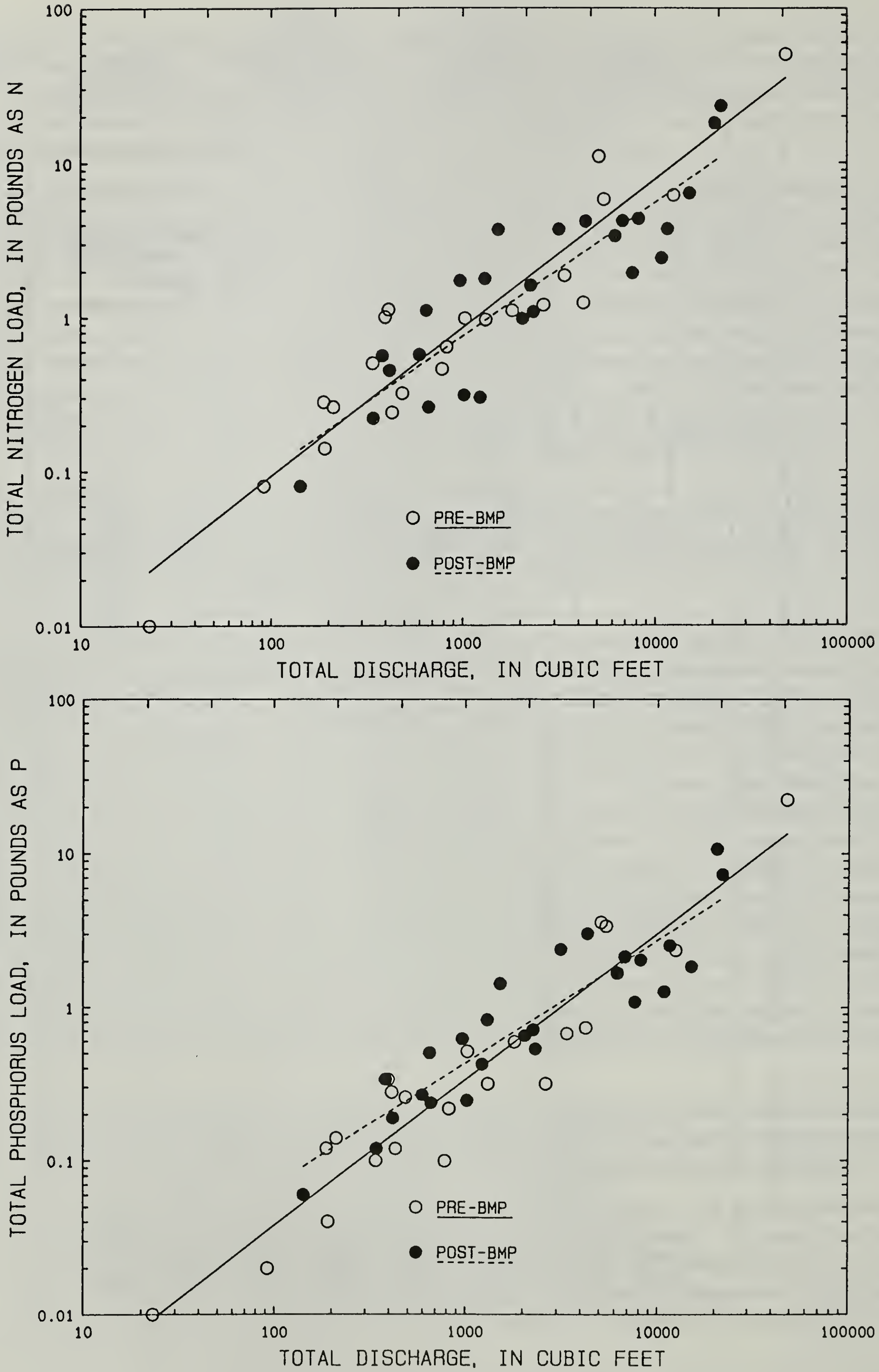


Figure 7.5-11.-- Total nitrogen and total phosphorus load as a function of pipe discharge from 27-terraced acres at Field-Site 2 for the pre-BMP (October 1984 through September 1986) and post-BMP (October 1986 through September 1988) study periods at Field-Site 2.

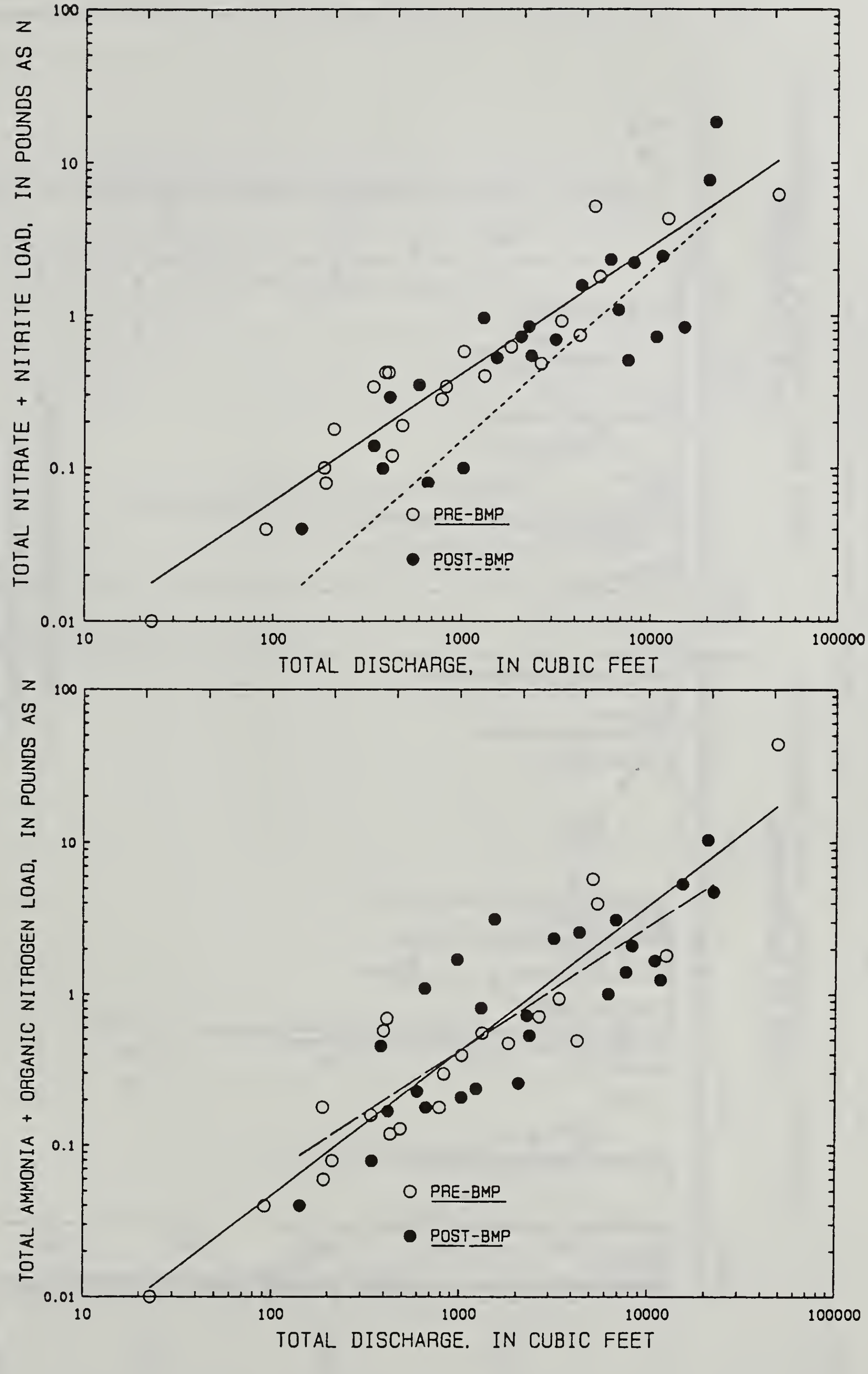


Figure 7.5-12.-- Total nitrate plus nitrite and total ammonium plus organic nitrogen load as a function of pipe discharge from 27-terraced acres at Field-Site 2 for the pre-BMP (October 1984 through September 1986) and post-BMP (October 1986 through September 1988) study periods at Field-Site 2.

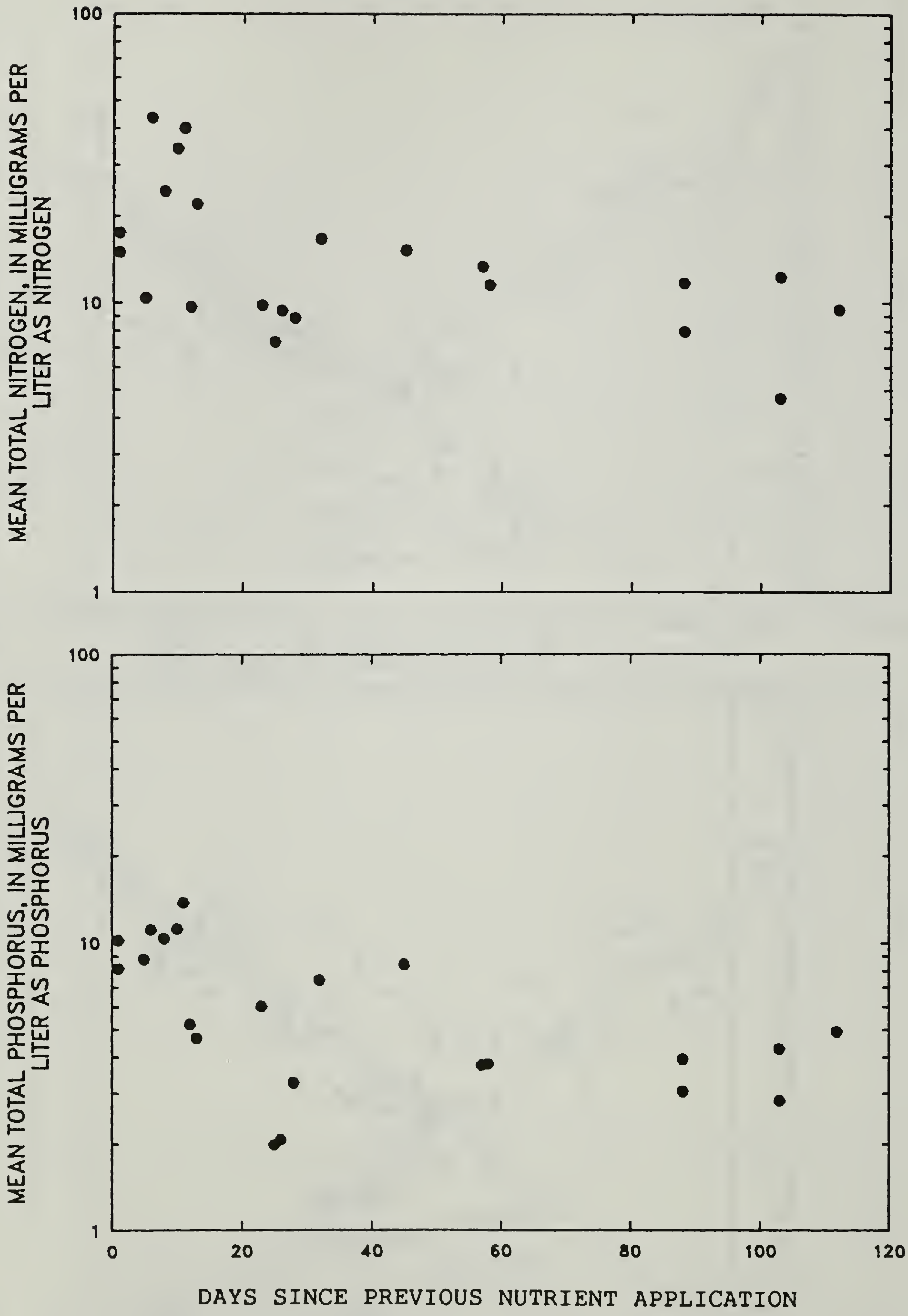


Figure 7.5-13.--Relation between mean total-nitrogen (above) and -phosphorus (below) concentrations and the number of days since the previous nutrient application for the pre-BMP period October 1984 through September 1986.

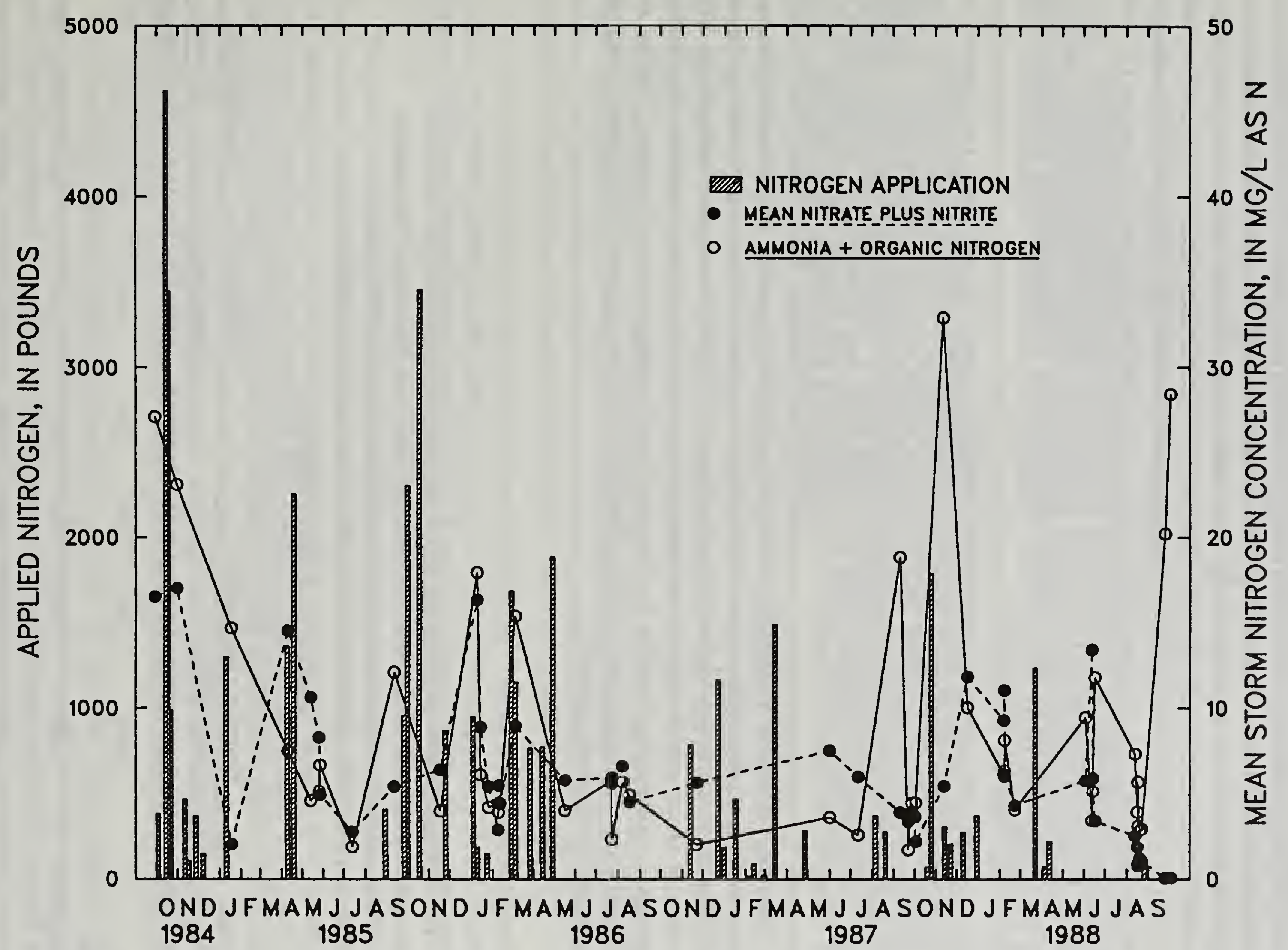


Figure 7.5-14.--Discharge-weighted mean total ammonia plus organic-nitrogen (above) and total nitrite plus nitrate (below) concentrations in discharge from, and nitrogen applied to the piped-drained tract.

nutrient availability. These variables were entered into multiple regression models to estimate a quantitative relation among mean-storm nutrient concentrations, climatic factors, and agricultural activities. Regressions were run on the complete dataset and on the thawed- and the frozen-soil data subsets. Significant explanatory variables were not found for either the complete dataset or the frozen-soil data subset. For the thawed-soil data subset, the relation between the number of days since the previous nutrient application and mean total-nitrogen and -phosphorus concentrations in discharge was significant (table 7.5-12). In general, mean concentrations of total nitrogen and total phosphorus in discharge decreased as the number of days since the previous nutrient application increased (fig. 7.5-13). However, mean total-phosphorus concentrations behaved asymptotically; there was no decrease in mean total-phosphorus concentrations in runoff as the number of days after the previous nutrient application increased beyond about 60 days (fig. 7.5-13). This asymptotic behavior suggested the existence of a baseline total-phosphorus concentration in the range of 2 to 5 mg/L. Mean total-nitrogen concentrations decreased as long as 120 days after the previous nutrient application. But, because the number of days between application and runoff was highly variable in both the pre-BMP and post-BMP periods, the statistical relation between nutrient concentrations and days since nutrients were applied was not useful in quantitatively determining the effects of BMPs on pipe-discharge water quality.

For the pre-BMP period, the regression procedures described above did not show the quantity of nutrients applied to be a significant explanatory variable. However, figure 7.5-14 gives some insight into the effect that the quantity of applied nutrients had on mean storm nutrient concentrations. Possible explanations for the lack of significance in the regressions of nutrient applications and mean storm nutrient concentrations are: (1) the relation between application quantities and mean storm concentrations is nonlinear, and (2) nitrogen available for transport in discharge was substantially different from actual nitrogen applications due to application method, volatilization, denitrification, and leaching into the soil. Of these factors affecting nitrogen availability, all but application method have time-dependent probabilities. That is, with increasing elapsed time after nitrogen application there is an increasing chance that one or more of these factors is or results in reducing nitrogen available for transport in discharge. This time-dependent behavior could explain why the number of days since the previous nutrient application was the only significant explanatory variable for the mean total-nitrogen concentrations. Despite the regression results, graphical evidence supports the hypothesis that nutrient concentrations in surface runoff are a function of quantity of nutrients applied.

Table 7.5-12.--Regression statistics for the log of mean storm total nitrogen species and total phosphorus concentration, in milligrams per liter, as a function of the number of days since the last nutrient application for the pre-BMP period (October 1984 through September 1986); thawed-soil conditions only

[n, number of storms; <, less than]

Dependent variable (log transformed)	n	Regression coefficient: Days since previous nutrient application	t-test	p-value	Intercept	Coefficient of determination (Adj. R^2)[1]	Standard error: Log units	Percent[2]: Plus	Percent[2]: Minus
Mean total nitrogen	16	-0.004	3.362	0.005	1.33	0.41	0.19	55	35
Mean total ammonia plus organic nitrogen	16	-.005	2.830	.013	1.02	.32	.26	82	45
Mean total nitrite plus nitrate	16	-.003	2.967	.010	1.01	.34	.17	48	32
Mean total phosphorus	16	-.006	4.857	<.001	.91	.66	.13	35	26

[1] Coefficient of determination (R^2) adjusted for degrees of freedom.

[2] Presented as described by Tasker (1978).

7.5.5 Field-Site 2 Ground-Water Quantity and Quality

A water-table map of the median water table altitude at Field-Site 2 for the period 1985-86 is shown in figure 7.5-15. The water-table configuration indicates that ground-water flow occurs from west to east, with discharging to Indian Run, although ground-water flow probably crosses all of the site boundaries. A zone of low aquifer transmissivity exists around well LN 1670.

Ground-water quality data are shown as annual (water year) boxplots in figures 7.5-16 to 7.5-21.

Specific conductances of ground-water at the site ranged from 450 µS/cm at well LN 1669, to 1,560 µS/cm at well LN 1676. Specific conductance is a measurement of charged ionic species in solution that may be present due to dissolution of site soils, regolith, and bedrock in addition to dissolution of organic material and agricultural chemicals applied to farm fields.

Concentrations of dissolved phosphorus ranged from the detection limit of 0.01 mg/L to 0.51 mg/L as P. The maximum concentration was measured at well LN 1673. Phosphorus, like ammonium, is essentially unavailable for leaching to ground water because it rapidly sorbs to soil particles at the land surface and in the unsaturated zone. Phosphorus was therefore determined to be a poor indicator of the effects of BMP implementation on ground-water quality. Phosphorus analyses were discontinued in 1989.

Concentrations of dissolved ammonia plus organic nitrogen in ground-water ranged from the detection limit of 0.20 to a maximum of 2.4 mg/L as N. The maximum concentration was measured at well LN 1676. Organic nitrogen decays through oxidation to ammonium. Concentrations of ammonia nitrogen were small because ammonium ions readily sorb to unsaturated zone materials, and do not easily leach to ground water. Sorbed ammonium subsequently oxidizes to soluble nitrate, which moves easily with infiltration water through the soil column to the water table.

All of the samples were analyzed for dissolved nitrite plus nitrate; most samples were analyzed for dissolved nitrate. Because 99.9 percent of the dissolved nitrite plus nitrate was nitrate, the analyzed nitrate plus nitrite concentrations are referred to as dissolved nitrate for all samples. Dissolved nitrate accounted for over 90 percent of the total nitrogen in the ground water at the site.

Dissolved nitrate ions do not sorb to soils under site soil pH conditions, and move conservatively with respect to infiltration to the water table. Because of the large percentage of total ground-water nitrogen that is nitrate, and the mobility of the nitrate ions in water, nitrate concentrations in ground water were the most appropriate ground-water indicators of the effects of BMPs on ground-water quality.

Nitrate concentrations in the ground water commonly exceeded the U.S. Environmental Protection Agency maximum contaminant level of 10 mg/L nitrate as nitrogen (U.S. Environmental Protection Agency, 1990), and ranged from a minimum of 7.4 mg/L at well LN 1669 to a maximum of 97 mg/L at well LN 1676.

Six wells and a spring were sampled monthly during nonrecharge conditions and during an average of three storms per year during recharge conditions (figs. 7.5-22 a-f). Results were grouped into nonrecharge and recharge groups. A sample was considered to be a nonrecharge sample if it was collected at least two weeks after a significant ground-water recharge event. A significant recharge event was defined as being a rise of 0.6 foot or greater in water level in the high-yielding wells and a rise of 1.0 foot or greater in water level in the low-yielding wells. A uniform rise could not be used for all wells since water levels responded less in the low-yielding wells than the higher-yielding wells during the same storm event. Samples collected from the spring LN SP61 could not be classified as nonrecharge or recharge because no water-level data were collected at the spring.

The recharge sample groups were used to assess: (1) how the water quality varied during short recharge periods compared to baseline or nonrecharge periods, and (2) to what extent does recharge water, which may be affected by agricultural activities and climatic factors, affect the overall quality of water in the system. Nitrate concentrations in ground-water samples can either increase or decrease in response to recharge as indicated by data collected at well LN 1677 during the November 1985 and July 1986 storms (figs. 7.5-23). Approximately four inches of rain in November 1985 (fig. 7.5-23), caused the ground-water level to rise by about two feet, and a concurrent increase in the concentration of nitrate in ground water by

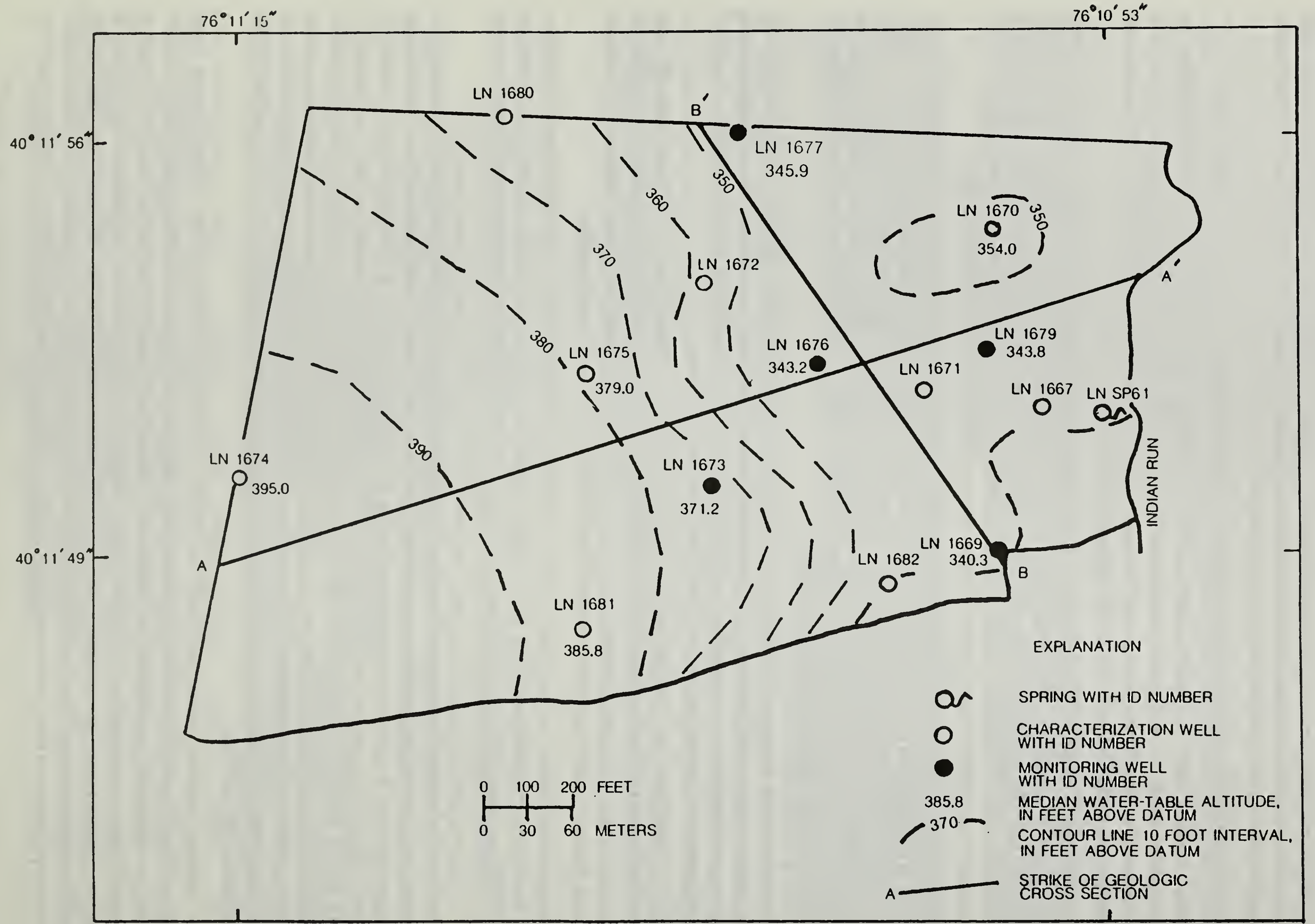
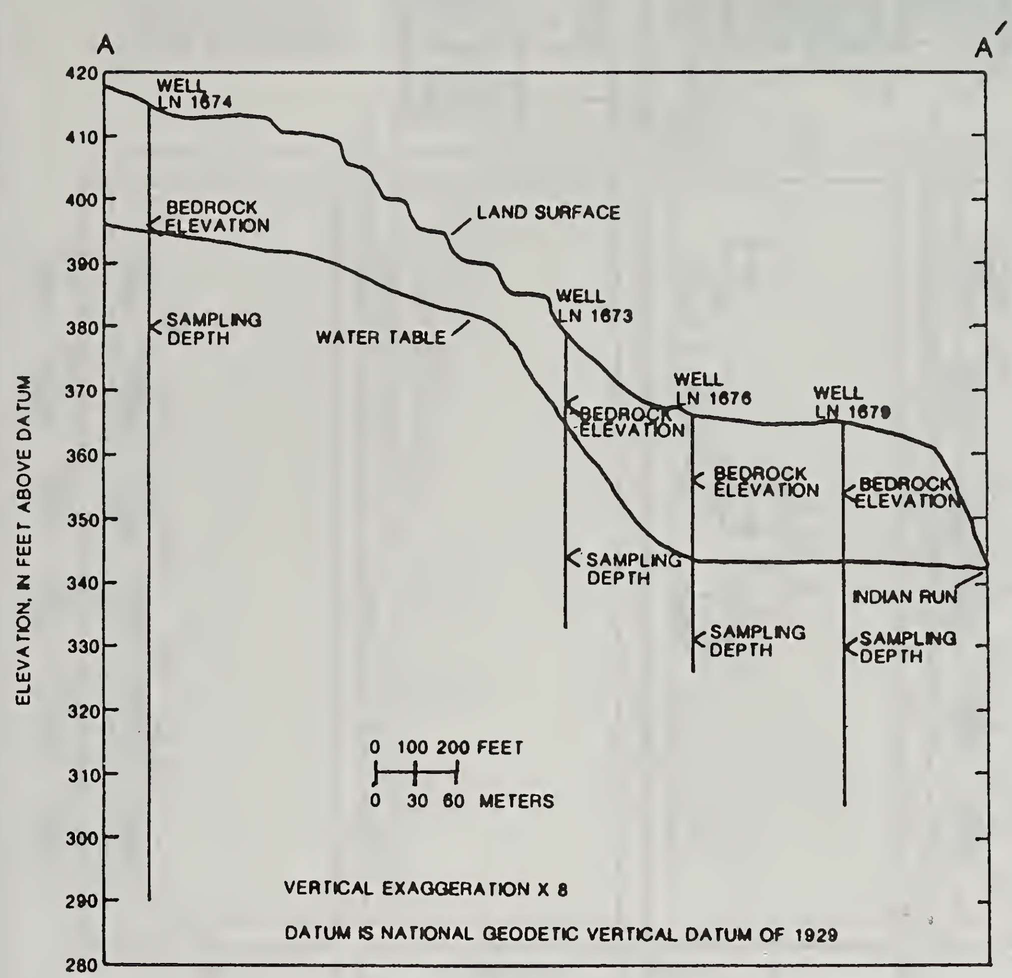


Figure 7.5-15A.--Median water table altitude at Field-Site 2 for the period 1985-86, with location of geologic cross sections (shown in figure 7.5-15B).



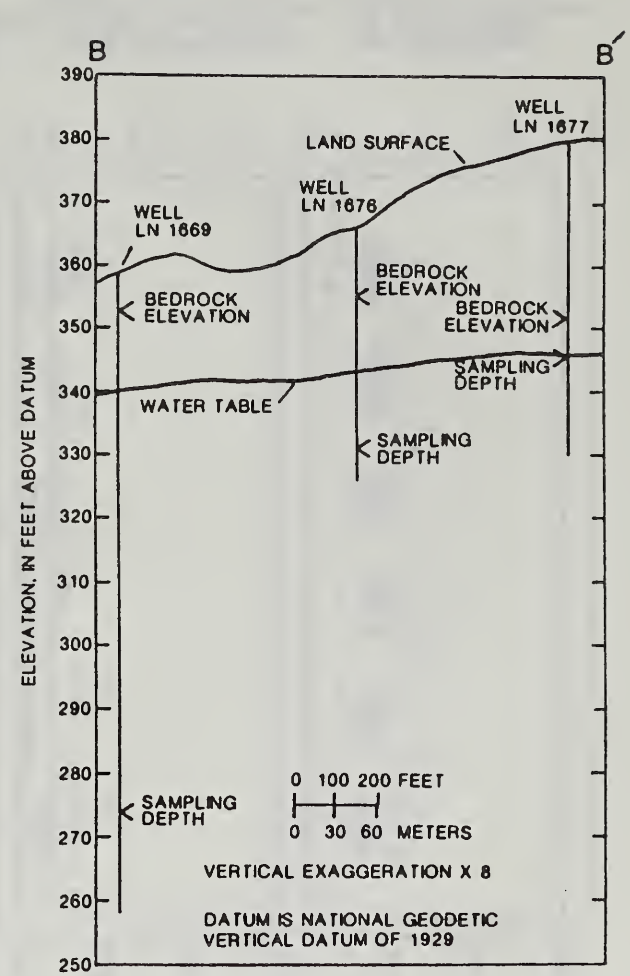


Figure 7.5-15B.--Geologic cross sections A - A′ and B - B′ (shown on figure 7.5-15A).

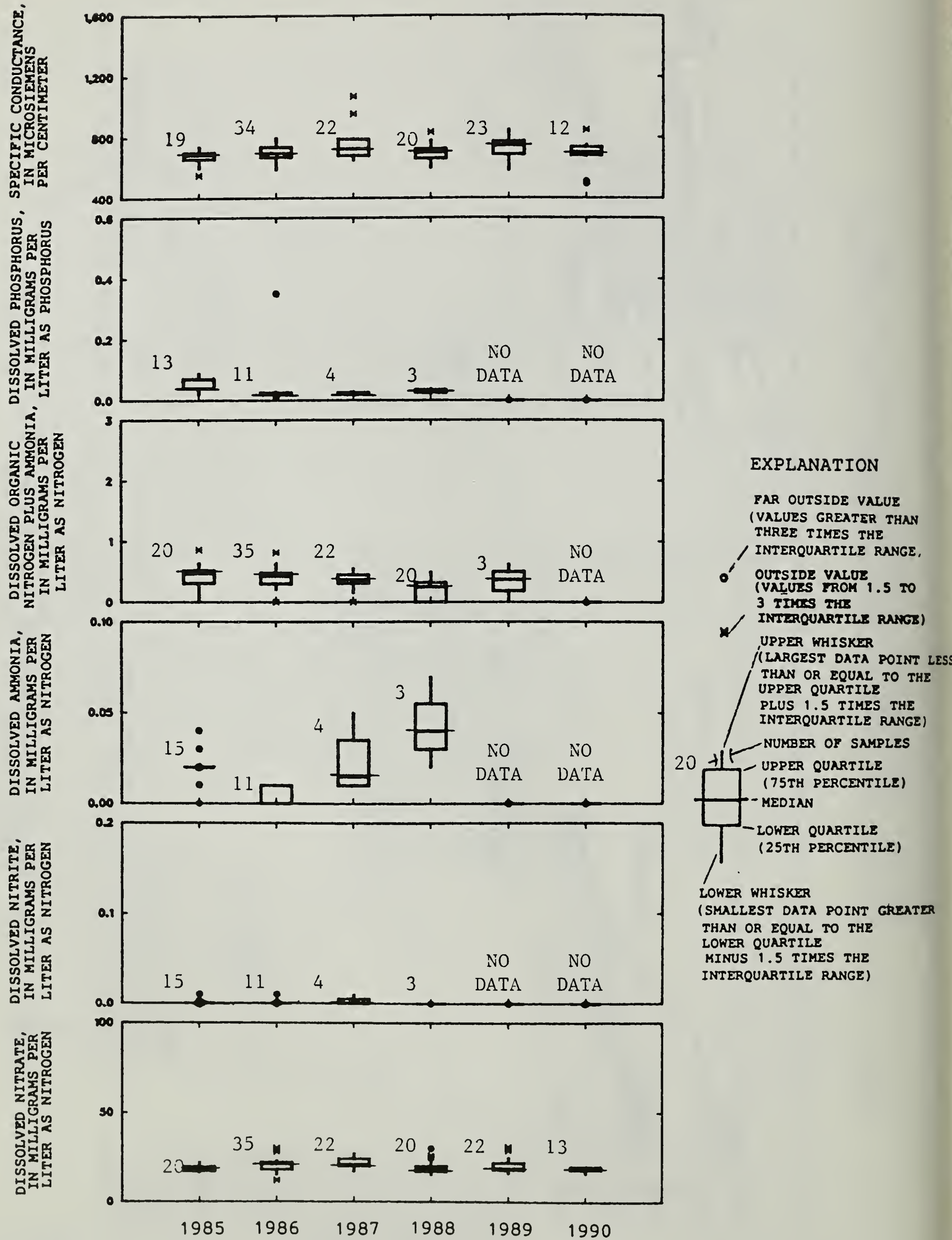


Figure 7.5-16.--Water quality data collected at spring LN SP61 during the study period (1985-90).

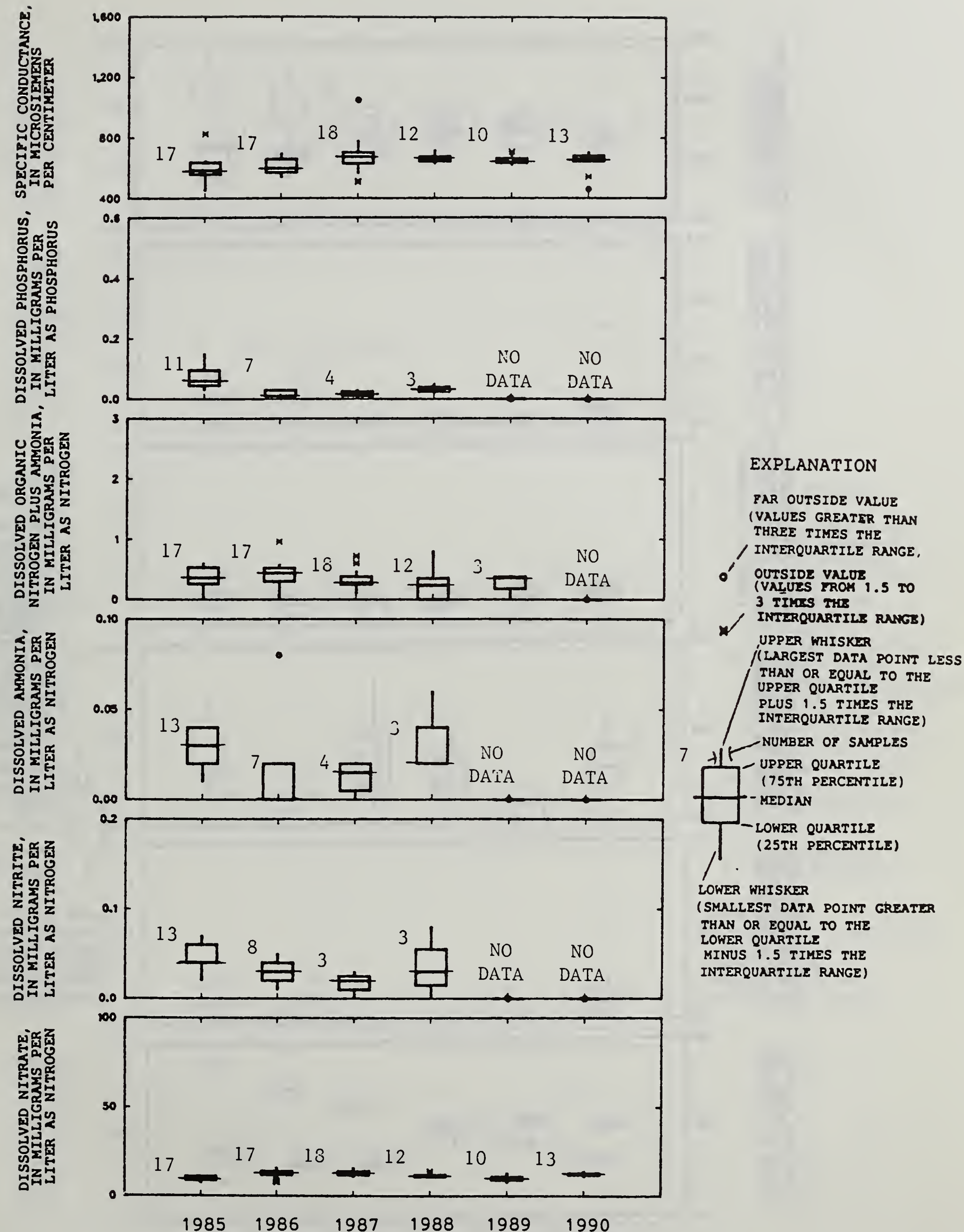


Figure 7.5-17.--Ground-water quality data collected at well LN 1669 during the study period (1985-90).

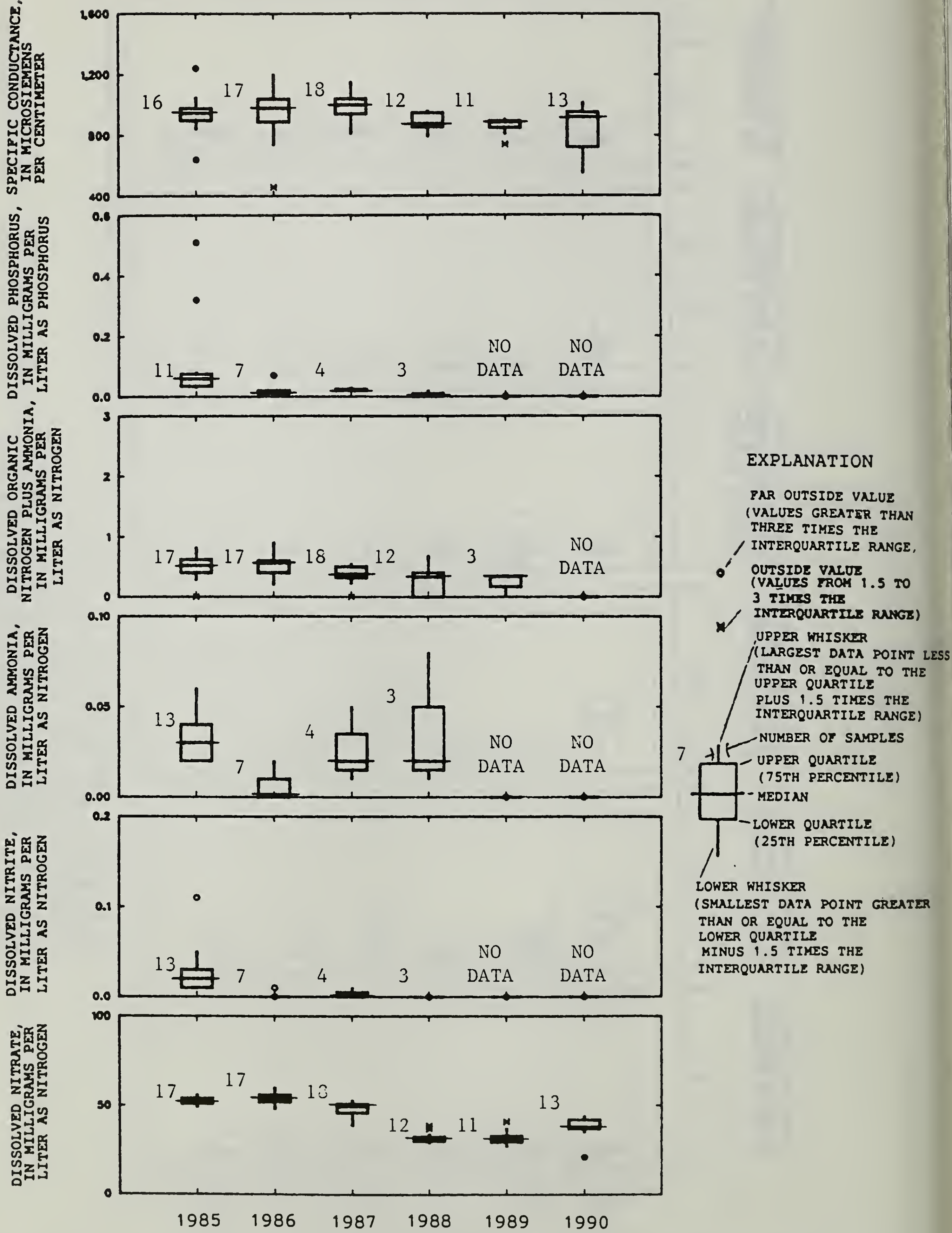


Figure 7.5-18.--Ground-water quality data collected at well LN 1673 during the study period (1985-90).

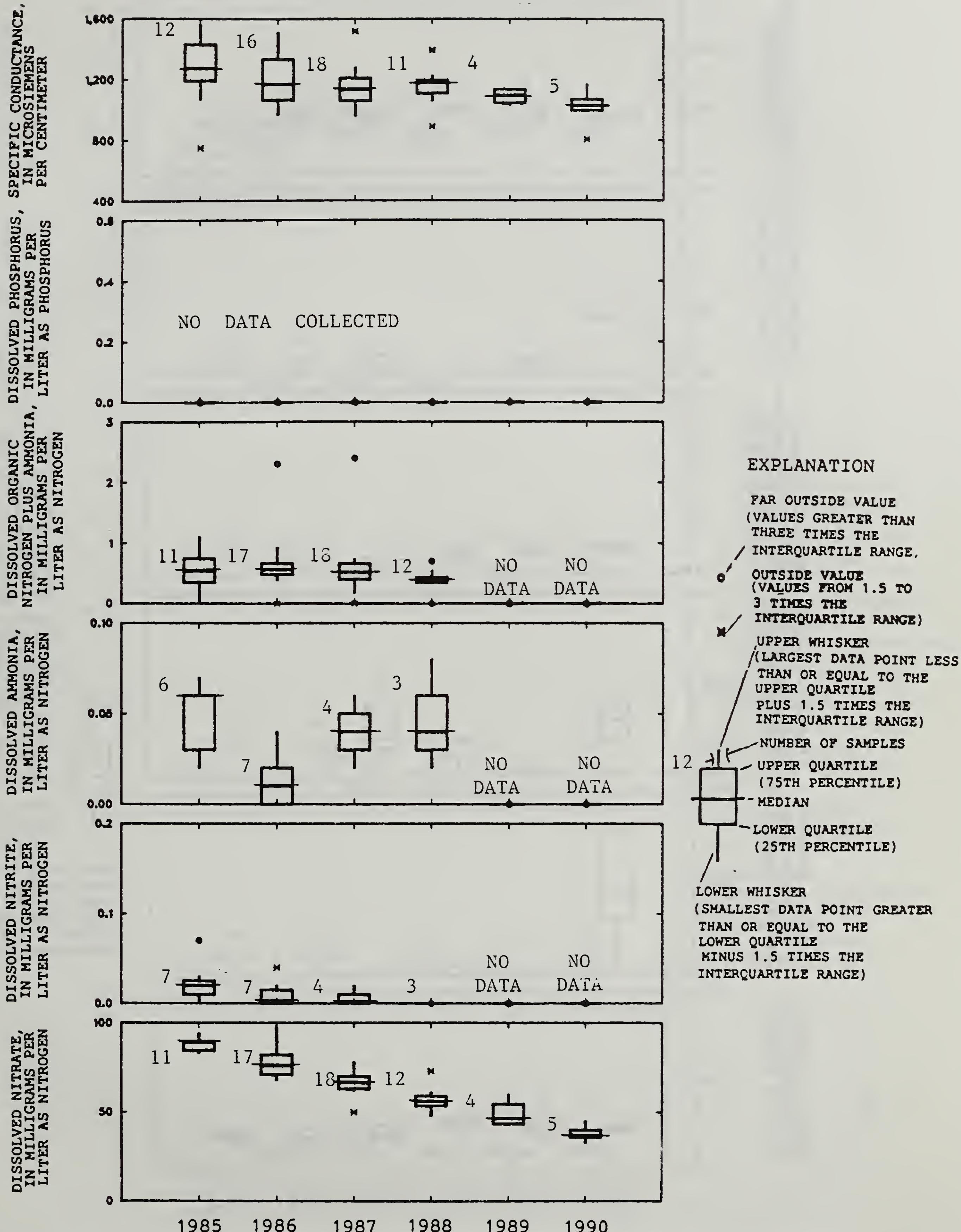


Figure 7.5-19.--Ground-water quality data collected at well LN 1676 during the study period (1985-90).

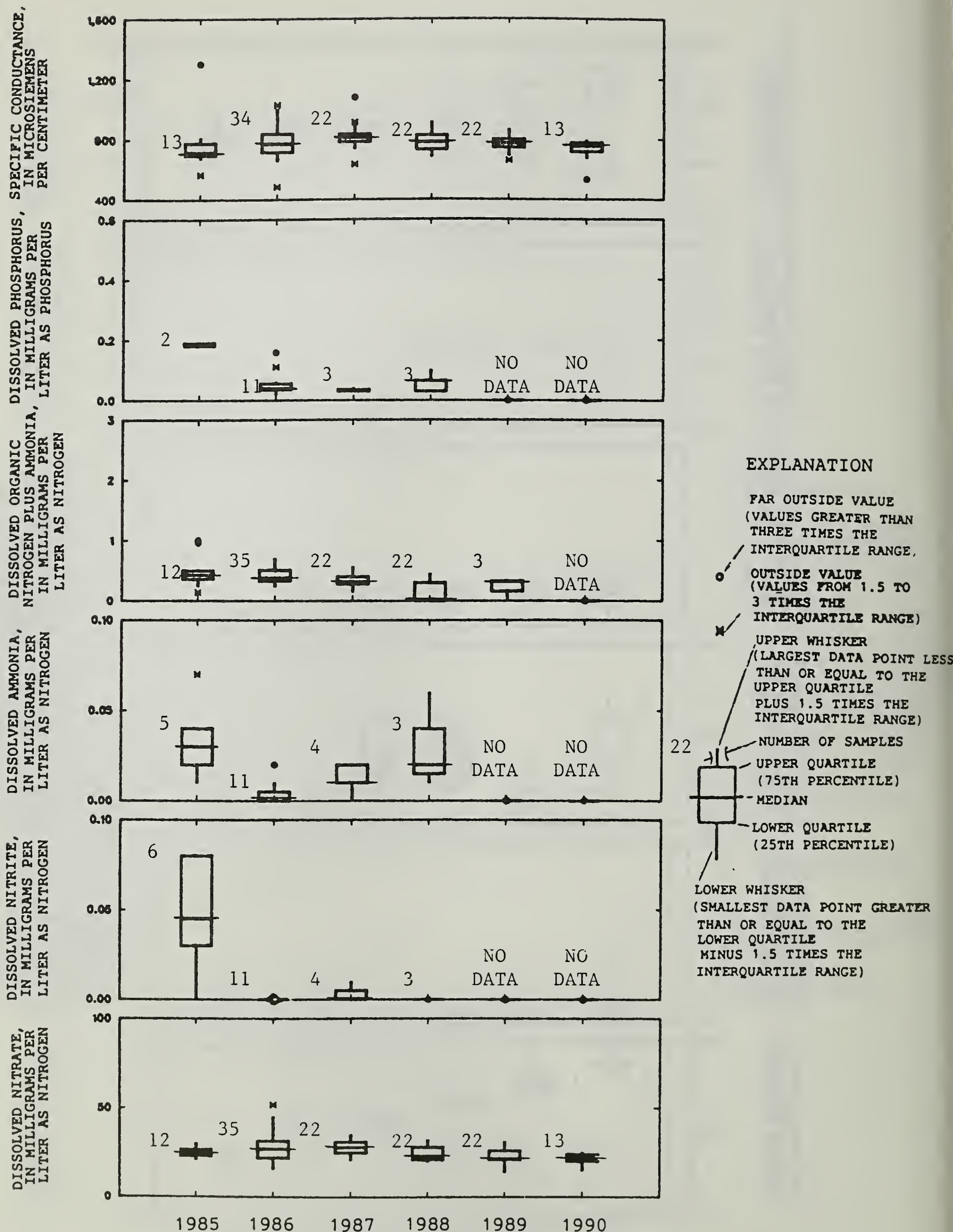


Figure 7.5-20.--Ground-water quality data collected at well LN 1677 during the study period (1985-90).

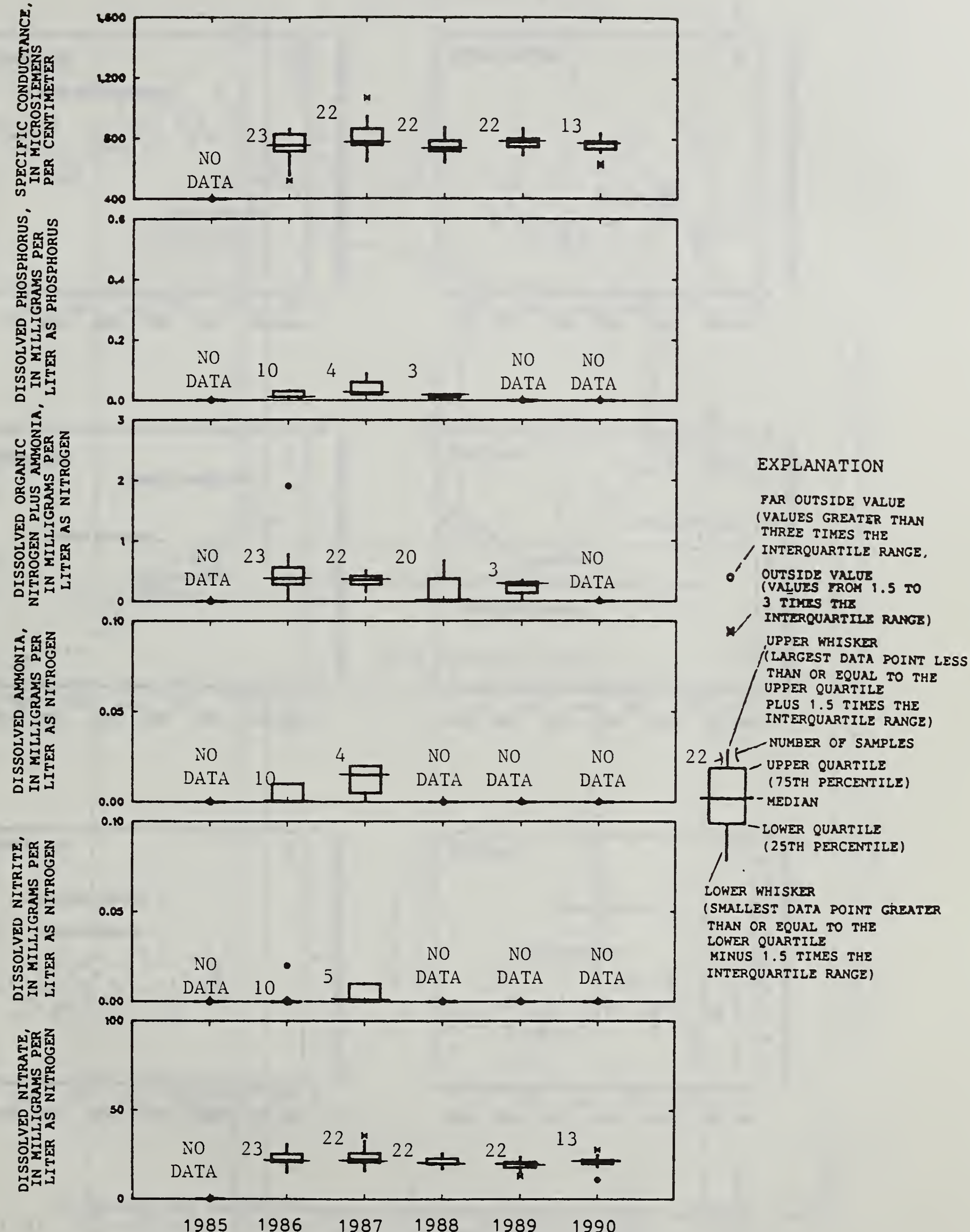


Figure 7.5-21.--Ground-water quality data collected at well LN 1679 during the study period (1985-90).

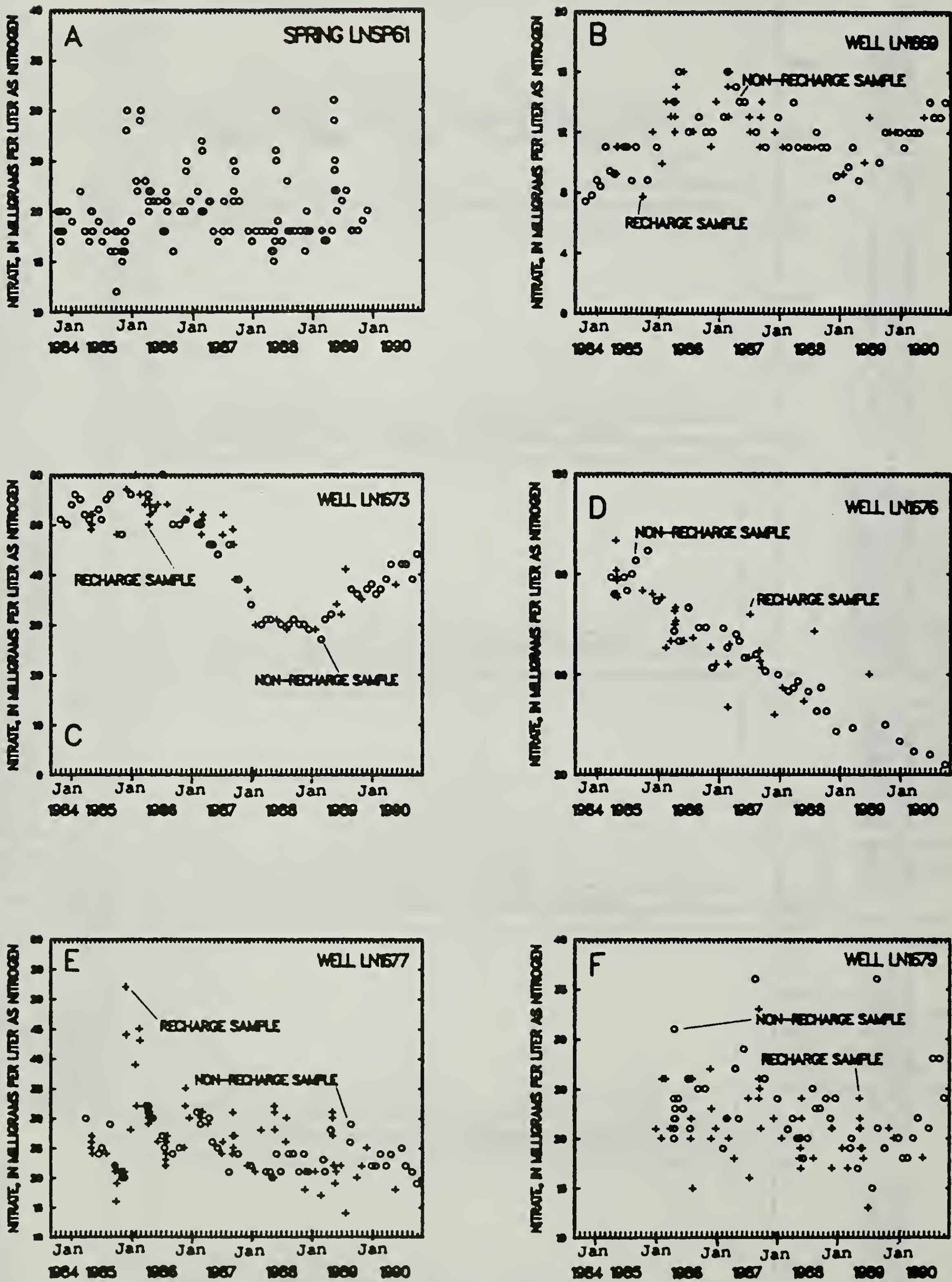


Figure 7.5-22.--Nitrate concentrations in ground water collected at spring LN SP61 and wells LN 1669, LN 1673, LN 1676, LN 1677, and LN 1679.

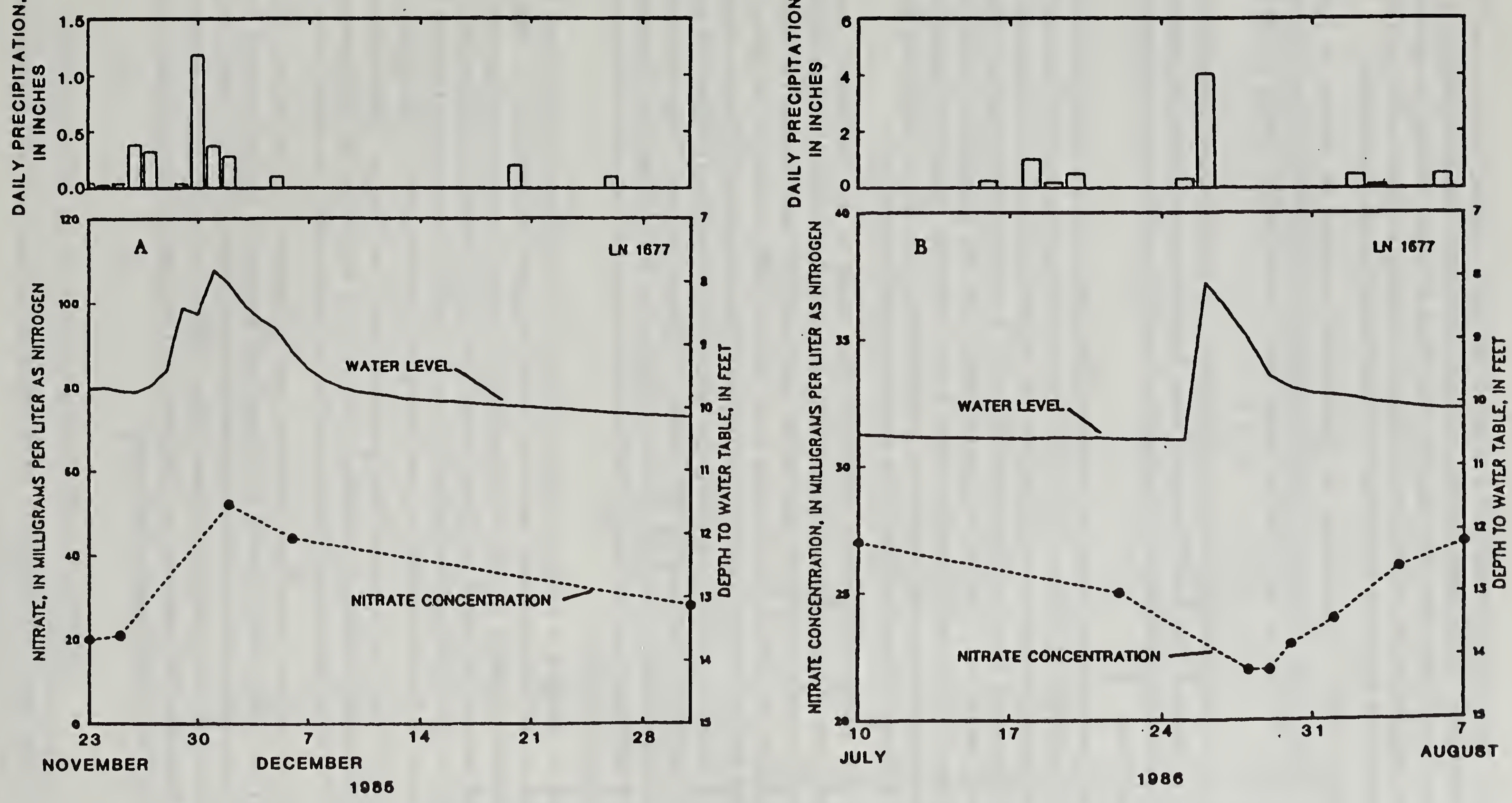


Figure 7.5-23.--Precipitation, water levels, and concentrations of nitrate in ground-water at well LN 1677 during two storms, November 1985 (A), and July 1986 (B).

about 25 mg/L. However, approximately 4 inches of rain from a similar storm in July 1986 (fig. 7.5-23) caused the water-table to rise about two feet, but concentrations of nitrate decreased by approximately 5 mg/L. These, along with other data showing the effects of storm recharge on ground-water nitrate concentrations, suggest that the availability of nitrogen for leaching to ground water with infiltration varies through time and is an important determinant of ground-water nitrate concentration.

Nonrecharge nitrate concentrations in ground-water samples are shown in figure 7.5-24. The nonrecharge sample group, consisting of samples collected at approximately equal time intervals during similar hydrologic conditions, were used for comparison of water quality during the pre-BMP and post-BMP periods.

Prior to the implementation of nutrient management, all animal wastes generated from the animal operations were disposed of on the 47.5 cropped acres. After the implementation of nutrient-management, the farmer exported all animal manure in excess of that quantity needed to meet nitrogen requirements for maximum crop yield.

Contributing areas were estimated for five monitoring wells in order to relate ground-water quality to the land-surface nitrogen applications (fig. 7.5-25). The contributing area to a well was defined as the area of diversion of ground water to the well along with any adjacent surface areas that provide recharge to the aquifer within the area of diversion (Morrissey, 1987, p. 10). For the purpose of this study, contributing areas were arbitrarily limited to a distance of approximately 1,000 feet upgradient of each well in order to determine an area of maximum influence of surface applied materials. Most of the variation in nonrecharge ground-water nitrate-sample concentrations in samples from each well was statistically explained by the amounts and timing of nitrogen applied in the contributing area of each well.

Manure- and commercial-fertilizer application data made to the contributing areas of the five monitored wells were summed to obtain annual nitrogen applications (table 7.5-13). Reductions in nitrogen applications that occurred from water year 1986 to water year 1987 were the result of the implementation of nutrient-management (table 7.5-13). In water years 1988 and 1989, for example, the farmer was permitted to apply either 5 tons of poultry manure per acre, supplying approximately 280 pounds of nitrogen per acre; 9,000 gallons of liquid hog manure, supplying approximately 410 pounds of nitrogen per acre; or 20 tons of steer manure, supplying approximately 340 pounds of nitrogen per acre. These recommendations were made to supply approximately 185 to 225 pounds of nitrogen per acre to crops after adjustments were made for estimated volatilization and rounding of load recommendations to conform with the spreading capacity of equipment used at the farm.

The effects of changes in loads of applied nitrogen on nonrecharge ground-water nitrate sample concentrations at the five monitored wells are shown in figures 7.5-26 and 7.5-27. Each point on the nitrogen-application graphs in figure 7.5-26 represents the sum of 4 months of applications. Points are not equally spaced because the points are plotted on the day of the maximum application in each 4-month period in order to provide a more representative curve. Typically, one large and several small nitrogen applications occurred in each contributing area during each 4-month period. The application-data points were then connected using a curve-smoothing procedure (poly3) on Telagraf[1] (1984) software. This simple and easily reproducible method of summing, plotting, and smoothing the nitrogen-application data produces a curve that approximates the nitrogen at the land surface that is available for leaching.

Statistically significant correlations (Spearman rank correlations, valid at the 90-percent confidence level; P-STAT, Inc., 1986) exist between the timing and amount of applied nitrogen and changes in nonrecharge ground-water nitrate sample concentrations (figs. 7.5-26 and 7.5-27). Nonparametric statistical procedures were used for all statistical analyses of data collected at the site because results of the Shapiro-Wilk test for normality (SAS Institute, Inc., 1982) indicated that ground-water nitrate data from wells LN 1673 and LN 1677 were nonnormally distributed.

1 Use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

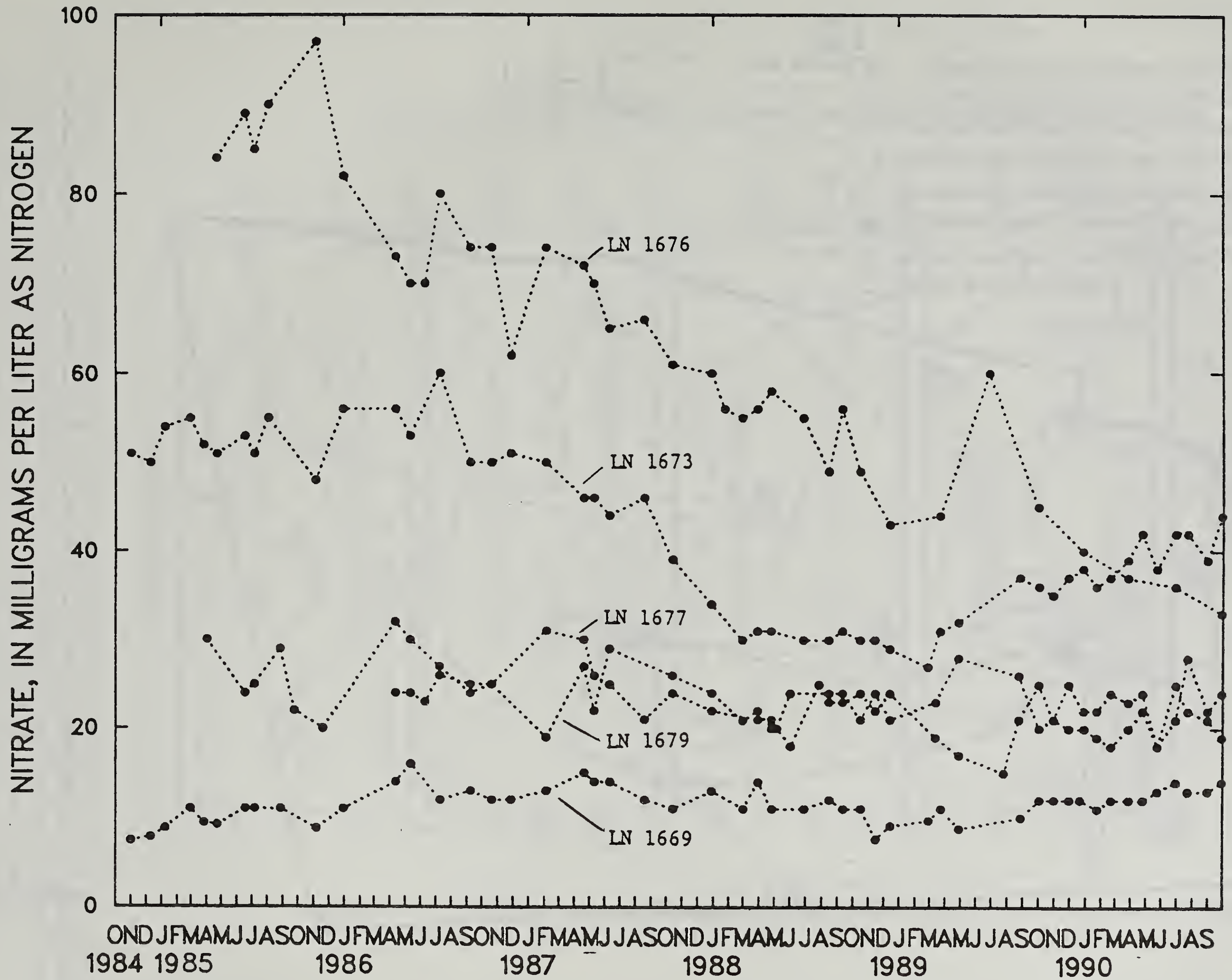


Figure 7.5-24.--Nitrate concentrations in nonrecharge samples collected at wells LN 1669, LN 1673, LN 1676, LN 1677, and LN 1679 from October, 1984 through September, 1990.

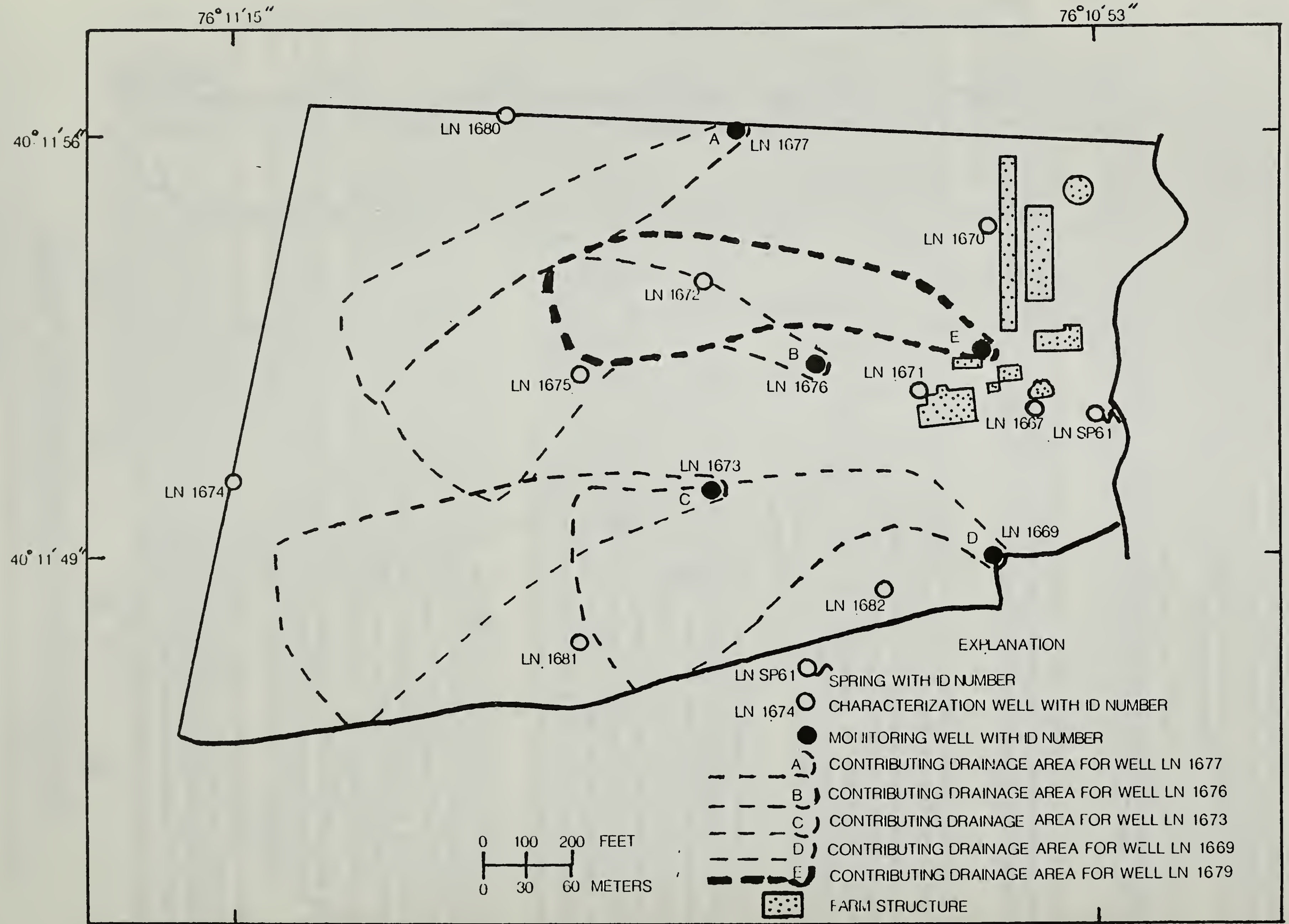


Figure 7.5-25.--Estimated contributing areas for five wells at Field Site 2.

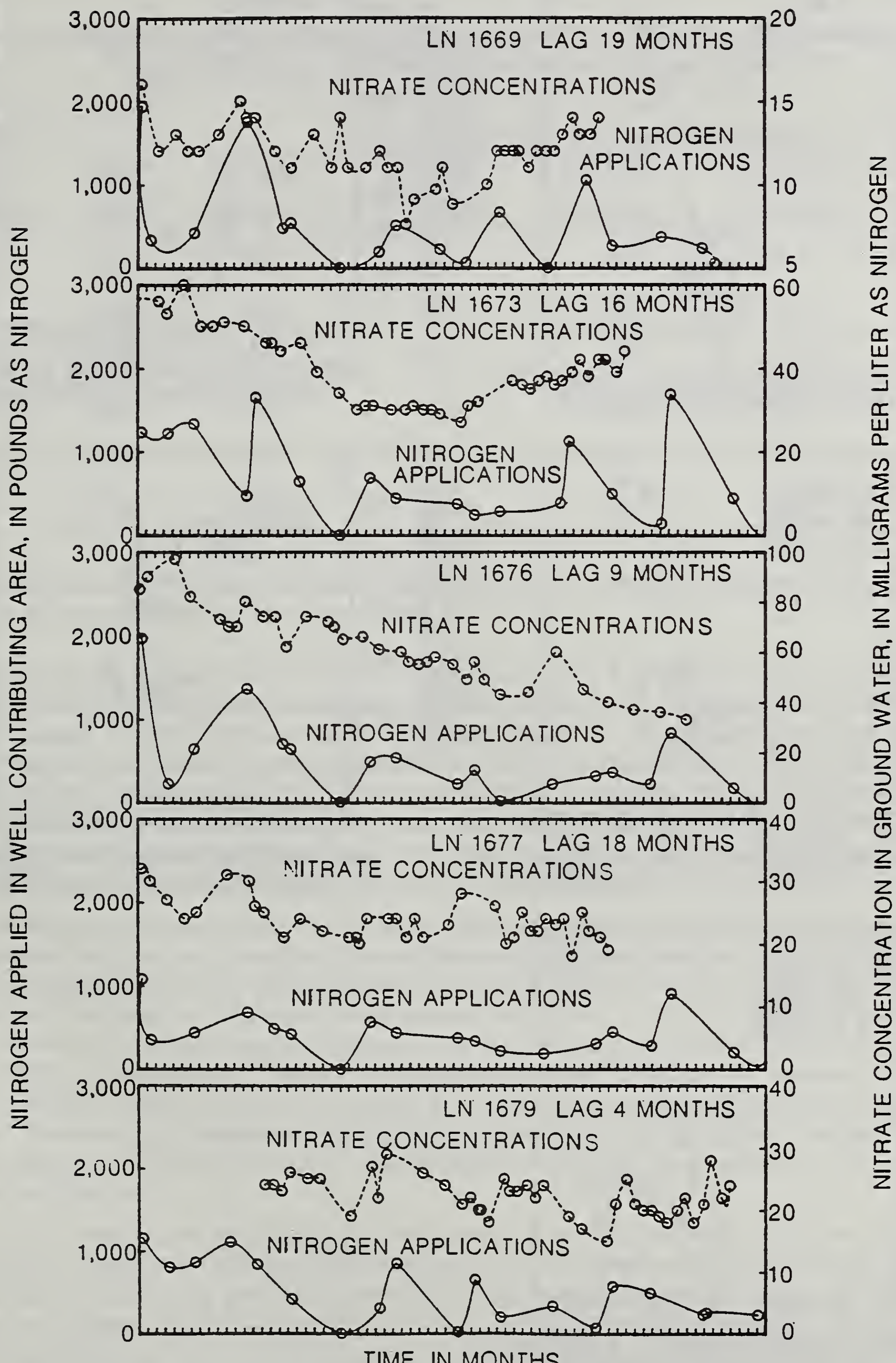


Figure 7.5-26.--Ground-water nitrate concentration data and applied nitrogen data for wells LN 1669, Ln 1673, LN 1676, LN 1677, and LN 1679 (to illustrate correlations, nitrogen applications have been moved to the right to match resultant nitrate concentrations; to get real-time relations, move the application curves to the left by the indicated time lag for each well).

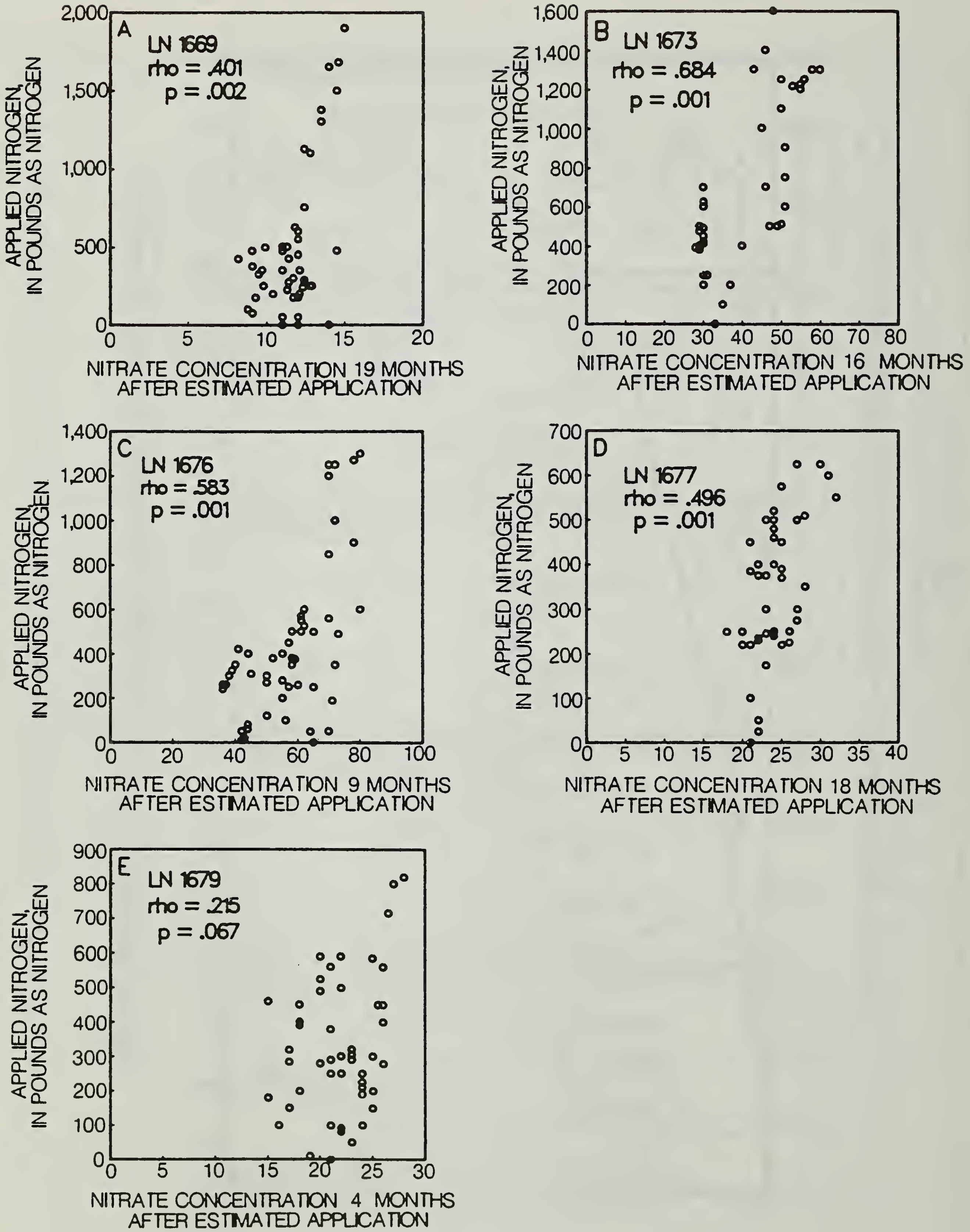


Figure 7.5-27.--Plots of ground-water nitrate concentration data and applied nitrogen data, and results of Spearman rank coorelation tests using data from wells LN 1669, LN 1673, LN 1676, LN 1677, and LN 1679.

Table 7.5-13.--Nitrogen in manure and commercial fertilizer applied in the contributing areas of five wells, in pounds of nitrogen per acre per year

Pre- or post-nutrient management	Water year[1]	Well (contributing drainage area) LN 1669 (5.6 acres)	LN 1673 (5.6 acres)	LN 1676 (5.5 acres)	LN 1677 (3.4 acres)	LN 1679 (4.1 acres)
Pre-	1985	580	670	570	550	830
Pre-	1986	390	490	440	470	430
Post-	1987	160	200	180	290	290
Post-	1988	130	160	150	310	290
Post-	1989	230	360	150	310	270
Post-	1990	120	380	180	340	160

[1] A water year is the 1-year period that begins on October 1 and ends on September 30. A water year is designated by the calendar year in which it ends.

Different amounts of time, from roughly 4 months for well LN 1679 to about 19 months for well LN 1669, are required for upgradient nitrogen applications to leach to the ground water at each of the wells. Long-term changes of nitrate concentrations in ground water are produced by the slow movement of recharge waters through the soil micropores under the influence of the pore-pressure gradient (Shuford and others, 1977; White, 1985; Gerhart, 1986). The time required for a nitrogen-rich or nitrogen-depleted "front" of water to travel from the land surface to the water table may vary in each contributing area as a function of unsaturated zone hydraulic conductivity, unsaturated zone clay content, the distance between the land surface and the water table, and flow through the carbonate bedrock.

The statistically significant, cause-effect relations between changes in rates of applied nitrogen manures and commercial fertilizers and changes in ground-water nitrate concentrations indicate that a significant amount of the nitrogen present in the applied manures and fertilizers becomes available for leaching and is transported with recharge to the ground-water system within 4 to 19 months following application. This process is consistent with estimates for nitrogen availability in manures presented by Graves (1986b), and Stevenson (1982), where 40 to 75 percent of the total nitrogen remaining in manure after storage is potentially available to the crops and for leaching to the ground water within the first year following application. Therefore, any substantial reduction or increase in rates of applied nitrogen will produce similar reductions or increases of nitrate concentrations in ground-water samples collected at the five monitor wells at the site.

Because the implementation of nutrient-management at the site resulted in decreases in amounts of applied nitrogen upgradient of all wells (tables 7.5-13 and 7.5-14), nitrate concentrations in ground-water samples collected during the pre- and post-nutrient management periods were tested for significant differences in median nitrate concentration using the Wilcoxon-Mann-Whitney test (table 7.5-14). Statistically significant decreases (at the 95-percent confidence level) in nitrate concentrations were detected for four of the five wells. The largest reductions in median nitrate concentration were detected at wells where ground water contained the largest pre-nutrient management nitrate concentrations. A statistically significant but small increase of approximately 1 mg/L was detected at the fifth well, LN 1669, after the implementation of nutrient management. Therefore, pre- and post-nutrient management nitrate concentrations in ground-water samples collected at the site indicate that nutrient-management planning was effective in reducing ground-water nitrate concentrations at the site, and that the reductions were greatest where the pre-nutrient-management concentrations were largest.

Table 7.5-14.--Average depth to water table, lag time, significance of Wilcoxon-Mann-Whitney test, pre-nutrient management, and post-nutrient management nitrate concentrations, percent change in median nitrate concentrations, and percent change in nitrogen applications at five wells

Well depth	Average depth to water, in feet, from land surface	Lag time	Sampling depth below water table surface	Wilcoxon-Mann-Whitney test, significant pre- to post- increase or decrease? (p-value)	Pre-nutrient management median nitrate concentration, in milligrams per liter	Post-nutrient management median nitrate concentration, in milligrams per liter	Percent change in median nitrate concentration	Percent change in applications, in pounds per acre per year
LN 1669	18	19 months	66	Significant increase (0.039)	11	12	+8	-67
LN 1673	10	16 months	23	Significant decrease (0.001)	53	37	-30	-53
LN 1676	24	9 months	10	Significant decrease (0.001)	82	56	-32	-67
LN 1677	30	18 months	3	Significant decrease (0.029)	26	23	-12	-39
LN 1679	20	4 months	13	Significant decrease (0.046)	24	22	-8	-60

7.5.6 Field-Site 2 Hydrologic Budget and Nitrogen Addition and Removal

Precipitation, runoff, ground-water recharge, ground-water inflow and outflow across site boundaries, and evapotranspiration are the major components of the water budget (table 7.5-15). Volumes were estimated as a percent of total annual recharge to ground water and ground-water inflow to the site based on steady-state simulations from a ground-water flow model. Methods used to measure or estimate the individual water budget components are described below.

Precipitation.--Precipitation was measured at the site using a rain gage equipped to record rainfall every 5 minutes. Precipitation averaged 41.7 inches from 1985-90 (table 7.5-15), which was slightly less than the average annual precipitation of 43.5 inches based on 30 years of record (1951-80) from the weather station at Ephrata (National Oceanic and Atmospheric Administration, 1982).

Runoff.--A gaging station was used to record surface runoff from 27 acres of the farm field from 1985-88. Total runoff volumes from the 27 terraced acres were doubled to obtain an estimate of surface runoff from the entire 55-acre farm, based on visual observations of storm runoff. The total estimated runoff for the 55-acre farm averaged approximately 3 percent of annual precipitation recorded at the site from 1985-88. Therefore, runoff was assumed to be 3 percent of annual precipitation during 1989-90, when the gaging station was not operational.

Ground water recharge.--Recharge to ground water from infiltration of precipitation was estimated from the water-level rise recorded in wells in response to storms as described by Gerhart (1986, p. 487). Rapid water-level rises following storms indicate that precipitation infiltrates quickly to the water table. Therefore, the water-level rise in a well multiplied by the specific yield of the geologic material in the vicinity of that well should provide a reasonable estimate of the ground-water recharge from that storm.

Recharge was computed using water-level observations and estimated specific yields at wells LN 1673 and LN 1677. These wells were selected because the water-level record for these wells was nearly complete for the entire study period. Prior to May 1985, the water-level rise in observation well LN 1673 was multiplied by a specific yield of 0.07 to estimate recharge. Recharge from the remaining storms was computed from the water-level rise and specific yield (0.06) of well LN 1677, at which the most complete water-level record was available for the period after May 1985.

Recharge estimates are very sensitive to the value of specific yield used in this computation. For example, if a specific yield of 0.05 were used (instead of 0.06) to compute recharge for the water year 1986, the estimated total recharge would be 16.9 inches, and would be equal to about 43 percent of the precipitation for that period as opposed to 20.3 inches, or 52 percent of the precipitation. Regardless of the specific yield value used, proportional differences in total recharge between years were significant.

Table 7.5-15.--Site water budget in terms of precipitation, ground-water inflow, runoff, evapotranspiration, and ground-water outflow, in inches

[Numbers in parentheses are percentage of total inflow or outflow.]

Water Year	Precipitation	+	Ground-water inflow	=	Runoff	+	Evapotranspiration	+	Ground-water outflow
1985	35.8 (84)		1.9 (16)		0.6 (2)		25 (66)		12.1 (32)
1986	38.8 (84)		3.5 (16)		0.3 (1)		18.2 (43)		24.0 (56)
1987	45.0 (84)		4.1 (16)		2.9 (6)		20.5 (42)		25.7 (52)
1988	40.4 (84)		3.7 (16)		1.3 (3)		19.6 (44)		23.2 (53)
1989	46.6 (84)		4.1 (16)		[1] 1.4 (3)		23.5 (46)		25.8 (51)
1990	43.6 (84)		3.4 (16)		[1] 1.3 (3)		24.7 (52)		21.0 (44)
Average	41.7		3.5		1.3		21.9		22.0

[1] Runoff estimated as 3 percent of precipitation based on average of 1985-88 data.

Recharge was estimated for each storm and summed by month to obtain annual recharge. The estimated recharge to the ground water averaged about 44 percent of the measured precipitation at the site during the years 1985-90. If the estimated recharge were evenly distributed throughout the entire study period, 1.54 inches would be recharged monthly. From figure 7.5-28, the importance of months with extreme recharge is evident. In the 1989 water year for example, 43 percent of the annual recharge occurred in May. Over the long term, most recharge could occur in any month if the timing, amount, and intensity of precipitation were favorable.

Evapotranspiration.--Water lost from the site as evapotranspiration can be computed as the residual term in the water budget. Evapotranspiration ranged from 42 percent of water outflow in 1987 to 66 percent of total outflow in 1985 (table 7.5-15).

Ground-water Flow Across Boundaries.--A ground-water flow model of the hillslope in which the site is situated was constructed to help estimate the magnitude of ground-water inflow and outflow across site boundaries. The hillslope was simulated as a two-dimensional, steady-state flow system in the x-y plane using the finite-difference model of McDonald and Harbaugh (1988). The finite difference grid, aquifer properties, and boundary conditions used in the model are shown in figure 7.5-29.

A simulated water table (fig. 7.5-30) from the model was compared with measured water levels from observation wells. Although the simulated surface does not fit the observed water levels exactly, the general configuration of the water-table surface was captured. The water budget computed by the model is based on the long-term average recharge from 19.1 inches of precipitation per year, estimated as 44 percent of the long-term average of 43.5 inches of precipitation per year recorded at Ephrata (National Oceanic and Atmospheric Administration, 1982). Ground-water inflow from 1985-90 was estimated as 16 percent of the total inflow of water to the site as indicated by modeling simulations (table 7.5-14 and fig. 7.5-31).

Ground-water recharge from the infiltration of precipitation and inflow across site boundaries was balanced by outflow across site boundaries and discharge to Indian Run. The boundaries of the ground-water flow system at the site are poorly defined. Because the site occupies only a part of a larger watershed, the northern, southern, and western boundaries of the site do not correspond to real physical boundaries.

7.5.6.1 Additions and removals of nitrogen

Additions and removals of nitrogen at Field-Site 2 were calculated each year of the study period. Annual amounts are shown in table 7.5-16 in addition to average quantities for the study period based on preliminary data analysis.

Additions of nitrogen to the site were manure nitrogen (93 percent of average-annual additions), commercial fertilizer nitrogen (4 percent of average-annual additions), nitrogen in precipitation 2 percent of average-annual additions), and nitrogen in ground water entering the site across the western boundary, (1 percent of average-annual additions).

Nitrogen was removed in harvested crops (38 percent of total removals), in ground-water discharge (38 percent of all removals), in volatilization gases (24 percent of removals), and in surface runoff (less than 1 percent of removals).

Soils at the site act as a sink for nitrogen applied to the site. Soil levels of nitrogen may increase in years of large nitrogen applications, and may decrease in years of small nitrogen applications. Because nitrogen applications decreased during the study as the result of nutrient management, soil levels of nitrogen probably decreased during the study period.

Potential errors may greatly influence the numbers reported in table 7.5-16, which should be read as a conceptual rather than quantitative estimate of nitrogen additions to and removals from the site. A brief description of methods of calculation and errors associated with each nitrogen addition and removal term follows.

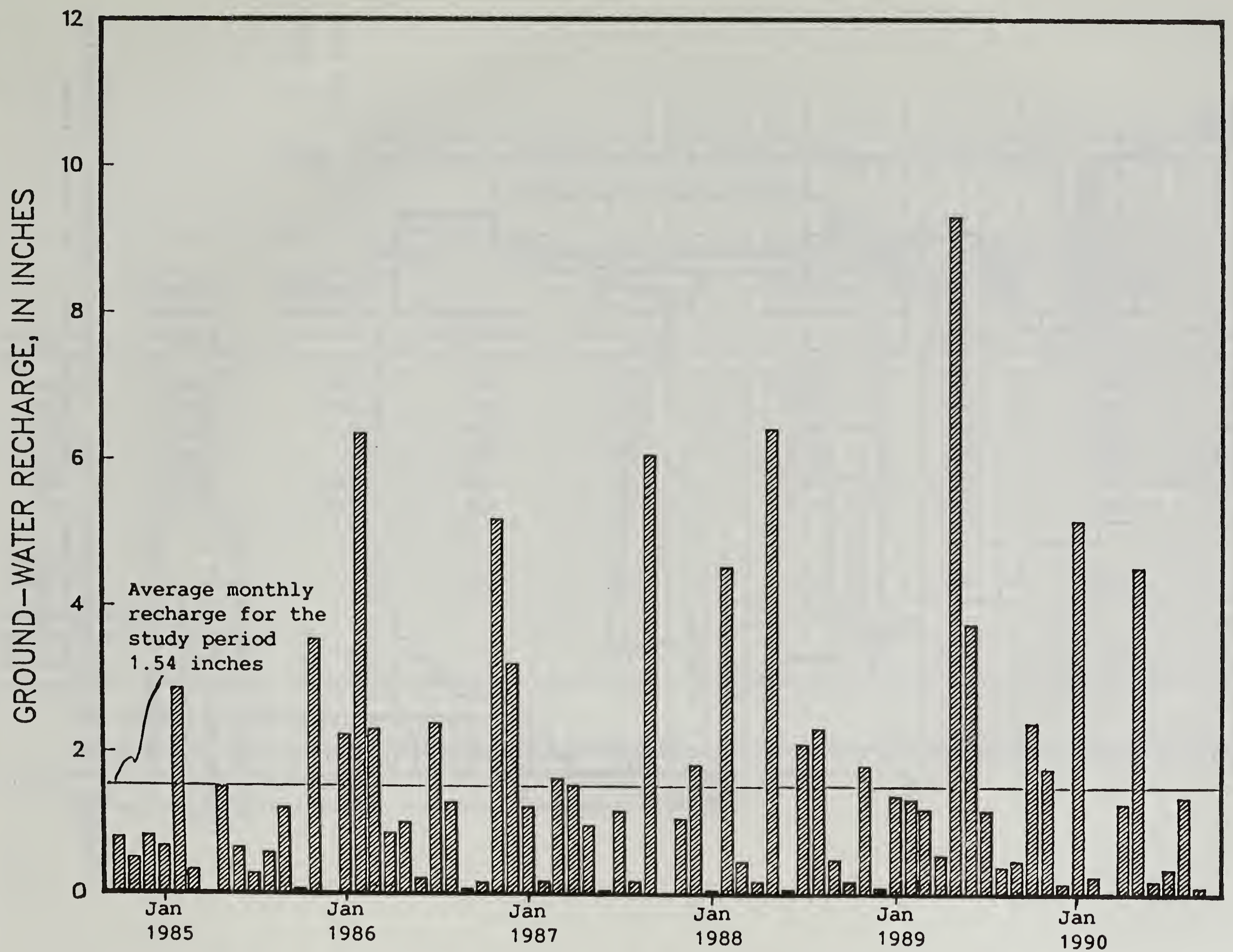
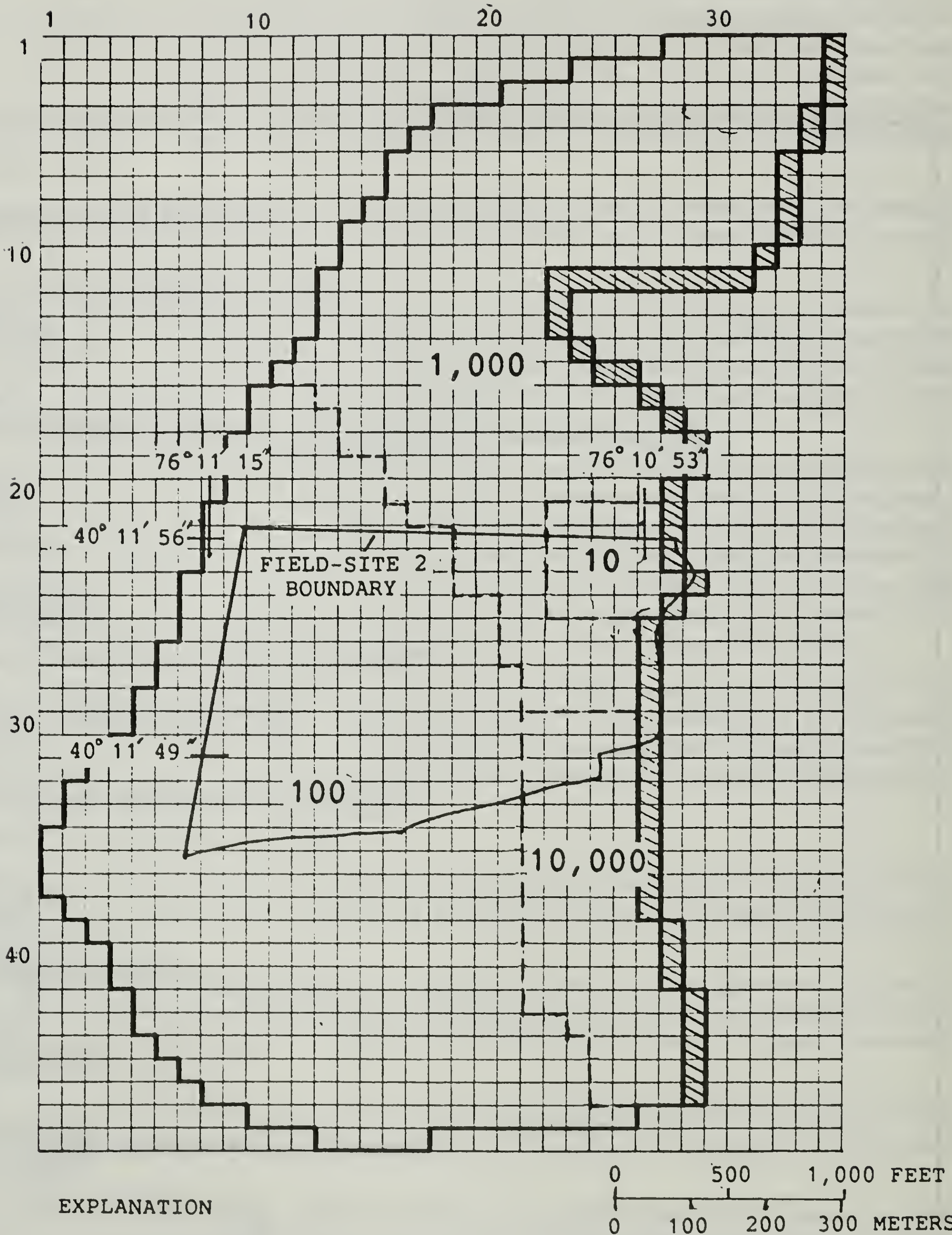


Figure 7.5-28.--Estimated monthly ground-water recharge, October 1984 through September 1990.



EXPLANATION

- CONSTANT HEAD BOUNDARY
- 1,000 TRANSMISSIVITY, IN FEET SQUARED PER DAY
- NO-FLOW BOUNDARY
- TRANSMISSIVITY BOUNDARY

Figure 7.5-29.--Finite-difference grid, hydrologic boundaries, and aquifer properties used in the ground-water flow model (from D.W. Risser, U.S.G.S.)

Table 7.5-16.--Estimated additions and removals of nitrogen at Field-Site 2

[Numbers are in pounds as nitrogen.]

	Additions				Removals			
Water year	Nitrogen in manure fertilizer	Nitrogen in commercial fertilizer	Nitrogen in precipitation	Nitrogen in ground-water inflow	Nitrogen consumed by crops	Surface-water loads of nitrogen	Ground-water loads of nitrogen	Volatilization
1985[1]	25,500	1,000	290	90	8,500	120	5,100	7,300
1986[2]	18,500	500	300	180	8,700	50	10,800	4,600
1987	11,500	0	390	190	6,900	20	10,500	4,400
1988	13,500	0	320	170	6,500	160	7,100	4,700
1989	17,200	1,600	330	190	7,400	[3]90	7,700	5,500
1990	16,700	1,700	340	160	8,100	[3]90	6,400	4,600
Average 1985-90			330	160	7,700	90	7,930	5,180
Percent of average annual additions or removals	93	4	2	1	38	<1	38	24

[1] 1985 and 1986 were prenutrient management.

[2] 1986 applications were unusually smaller than 1985 applications due to less manure disposal as the result of an outbreak of avian influenza in Lancaster County, which significantly reduced the number of animals present on the farm.

[3] Estimated as average of surface-runoff loads calculated for years 1985-88.

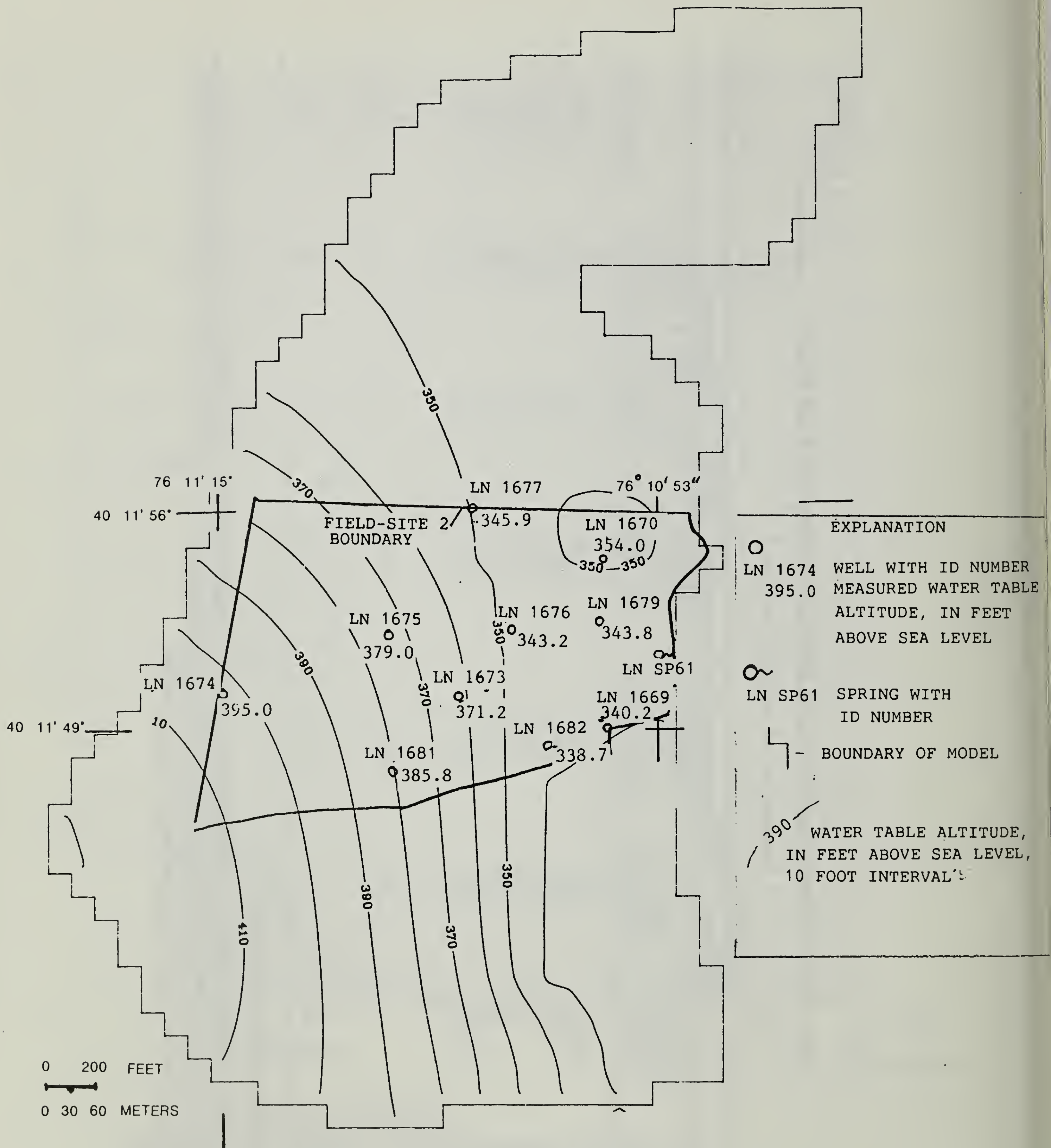


Figure 7.5-30.--Simulated water-table surface at Field-Site 2 and surrounding area.

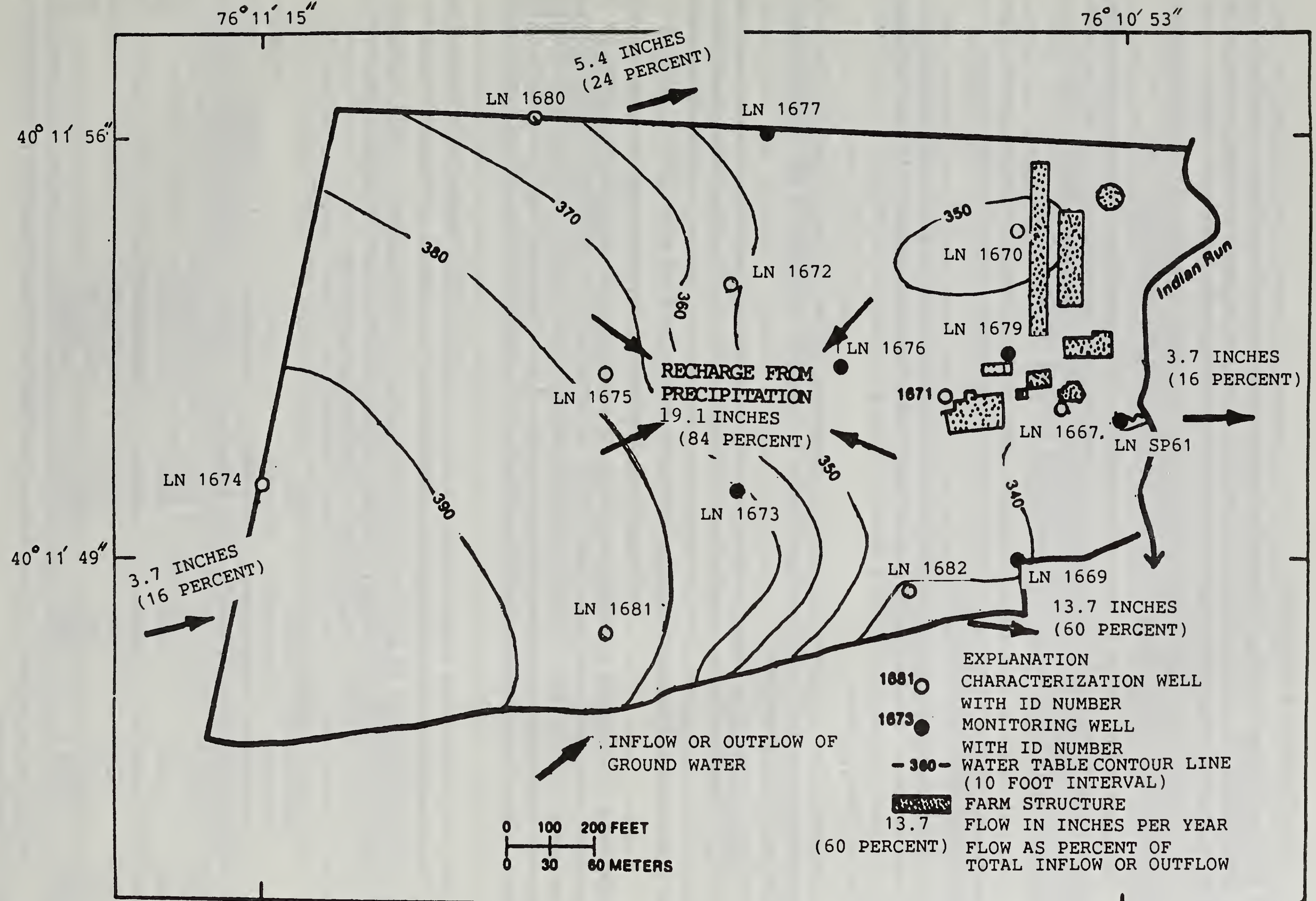


Figure 7.5-31.--Estimated water budget at Field-Site 2.

7.5.6.1.1 Additions of nitrogen

Manure Nitrogen: The major addition of nitrogen to the site is manure from the farm cattle, swine, and poultry operations. Loads of nitrogen in manure were estimated using application data supplied by the farmer and laboratory analysis of manure samples collected at the site during the study period.

After nutrient management was implemented in 1987, applications of nitrogen in manure decreased by about one-third from the pre-nutrient to post-nutrient management periods (table 7.5-16).

Estimation Errors: Potential errors in the calculation of the quantities of manure nitrogen applied include inaccuracy and variability of the reported quantities applied and variability in the nitrogen content of the manure. Manure amounts are typically reported as numbers of loads in a spreader. A load may mean the spreader was filled to overflowing or may mean it was filled nearly to capacity.

Variability in the nitrogen content of manure causes additional error. The nitrogen content of each manure was based on the average of analyses from several samples collected at different points in the animal confinement areas (table 7.5-1).

Commercial Fertilizer Nitrogen: Applications of commercial fertilizer to the site were small relative to the large amounts of manure nitrogen applied (table 7.5-16). Most of the commercial fertilizer used at the site was either starter fertilizer applied at the time of planting, or a sidedress of nitrogen to crops made early in the crop growing season.

Estimation Errors: Reported applications of commercial fertilizer nitrogen are probably reasonably accurate, as information about the nitrogen content and quantity of the fertilizer are typically available when the fertilizer is purchased.

Precipitation Nitrogen: Nitrogen in precipitation is in the form of ammonium and nitrate ions. Loads of nitrogen entering the site in precipitation (table 7.5-16) were calculated using volumes of precipitation estimated from rain gage data at the site multiplied by concentrations of the nitrogen content of ammonium and nitrate in precipitation samples in Pennsylvania reported by Lynch and others (1985-89) (table 7.5-17).

Estimation Errors: Errors in the measurement of precipitation at the site gage are small. A much greater error in the budget is possible from using the ammonium and nitrate values reported for the Lancaster County area by Lynch and others (1985-89) that were used for the calculation of loads of nitrogen in precipitation. Precipitation in farm areas with large animal operations are sites of the active volatilization of manure nitrogen. Measurements of the nitrogen content of precipitation were made at a chicken and hog farm in Adams County, Pennsylvania (Michael Langland, U.S. Geological Survey, written communication,

Table 7.5-17.--Calculation of annual nitrogen loads in precipitation, using annual nitrate and ammonium concentrations reported by Lynch and others (1985-89), and precipitation quantity data from the site

[mg/L, milligrams per liter; pounds of nitrogen in precipitation were calculated by multiplying total ammonium plus nitrate concentrations (as nitrogen) by annual precipitation (in liters) and a milligram to pound conversion factor (2.205×10^{-6} pounds per milligram)]

Water year	Annual dissolved ammonium concentrations as N, in mg/L	Annual dissolved nitrate concentrations as N, in mg/L	Total ammonium plus nitrate as N, in mg/L	×	Annual precipitation in liters	× $\left(\frac{1\text{g}}{1000\text{mg}}\right)\left(\frac{2.205\text{lb}}{1000\text{g}}\right)$ =	Annual pounds nitrogen in precipitation
1985	0.19	0.45	0.64		202,624,000		290
1986	0.19	0.44	0.63		219,528,000		300
1987	0.20	0.50	0.70		254,637,000		390
1988	0.23	0.41	0.64		228,461,000		320
1989	0.19	0.38	0.57		263,230,000		330
1990*	0.19	0.43	0.62		246,439,000		340

* 1990 data is not available at the time this article was written. Concentrations used for 1990 are the average of the previous five years.

1991). Precipitation showed elevated concentrations of nitrogen, primarily in the form of ammonia. Concentrations were gradationally lower as distance from a lagoon used for manure storage increased. The maximum concentrations of ammonia in precipitation in the Adams County study was 4.1 milligrams per liter (as nitrogen). This concentration is significantly larger than values reported by Lynch and others for Adams County Pennsylvania, and elevated values were directly attributable to volatilization of manure from the lagoon. Because Field-Site 2 has a manure storage facility and is the site of a concentrated animal population, the site could easily have an elevated precipitation-nitrogen load relative to the those calculated using the regional ammonium and nitrate in precipitation estimates of Lynch and others.

Nitrogen in Ground-Water Inflow: Nitrogen in ground-water inflow was estimated from the volume of water estimated by the ground-water model to enter the site across the western boundary during an average year multiplied by the mean nitrate concentrations of two ground-water samples collected in March 1985 and April 1988 from well LN 1674 on the western site boundary.

Estimation Error: While there is undoubtedly error involved in using only two samples to estimate the nitrate concentrations of ground water entering the site across the western boundary, this budget term would remain small even if nitrate concentrations were considerably larger due to the relatively small quantity of water that is estimated to enter the site across the western boundary.

7.5.6.1.2 Removals of nitrogen

Nitrogen in Harvested Crops: Nitrogen removed from the site in corn, tobacco, rye, and Sudan grass were calculated using yield-based estimates of nutrient consumption by crops supplied by the Pennsylvania State University Cooperative Extension (Robert Anderson, written communication, 1989). Nitrogen removed from the site in fruits and vegetables were estimated based on discussions contained in *Knott's Handbook for Vegetable Growers* (1962). Estimated annual nitrogen removals in harvested crops are shown in table 7.5-16.

Estimation Errors: This term is subject to errors from nonrepresentative determinations of crop nitrogen content and nonrepresentative determinations of crop yields.

Volatilization of Nitrogen: Volatilization of nitrogen from the site was estimated as a percentage of nitrogen applied (table 7.5-16). For surface-applied manure applications, 40 percent of the nitrogen was assumed to be lost to volatilization. For injected manure applications, 20 percent of the nitrogen was assumed to be lost to volatilization. These estimates were based on discussions contained in the Pennsylvania Department of Environmental Resources *Field Application of Manure* manual (Graves, 1986). Commercial fertilizer was estimated to volatilize at a rate of 15 percent of applications, an estimate based on discussions by Pionke and Urban (1985).

Estimation Errors: Quantification of the volatilization of nitrogen in manure and commercial fertilizer nitrogen is difficult. Losses of nitrogen due to volatilization are affected by air temperature, humidity, manure type, manure texture and moisture content, timing of incorporation into soil, and any factor influencing bacterial activity associated with volatilization. The percentage of nitrogen volatilized at the site could therefore be expected to vary greatly. Estimated losses of nitrogen due to volatilization of manure, reported by (Graves, 1986b) for manure treatment, handling, and field application, range from 10 to 90 percent.

Nitrogen in Runoff: Loads of nitrogen discharged from the site in surface runoff were calculated using discharge-weighted mean-storm nitrogen concentrations for each storm multiplied by measured water discharge. Because there is relatively little surface runoff from the site, removals of nitrogen in surface runoff account for less than 1 percent of nitrogen removed from the site.

Estimation Errors: Probable amounts of error associated with calculation of nitrogen loads in runoff would have a small effect on the magnitude of this term.

Nitrogen in Ground-Water Outflow: Preliminary estimates of nitrogen loads in ground water were calculated from estimates of monthly ground-water discharge multiplied by an estimate of nitrate concentrations in monthly ground-water samples.

Because ground water discharges across the northern, eastern, and southern site boundaries, and nitrogen concentrations in samples collected at wells vary spatially and temporally, nitrogen loads in ground water were computed for water discharging across each of the northern, eastern, and southern boundaries. The estimated monthly loads were then summed to obtain the total monthly and annual nitrogen loads in ground water from the site (table 7.5-16).

The quantity of ground-water discharged annually across each site boundary was computed by multiplying the total annual discharge from the site (annual recharge from precipitation plus flow into the site across the western boundary) by the percentage of annual flow estimated to cross each site boundary indicated by output from the ground-water model (figure 7.5-31). Annual discharge across each site boundary was then proportioned among months using water-level hydrograph rises for each month divided by the total annual water level rise to obtain the fraction of annual discharge for each month.

Samples from wells located in different parts of the site were chosen to characterize the quality of the ground-water discharges. Samples from well LN 1677 were chosen to characterize the nitrogen concentrations of water discharged across the northern boundary (fig. 7.5-31), samples from wells LN 1676 and LN 1679 were chosen to characterize the nitrogen concentrations of water that discharged across the eastern boundary, and samples from wells LN 1673 and LN 1669 were chosen to characterize the nitrogen concentration of water that discharged across the southern boundary. Monthly nonrecharge samples from these wells were selected to represent monthly nitrate concentrations in the ground water. If no nonrecharge samples were collected, then the median of all recharge-influenced samples were used during that month.

Liters of ground-water discharge were multiplied by milligrams per liter of nitrate in ground-water samples to obtain loads of nitrogen. Loads of nitrogen were then reported in pounds using a milligram to pound conversion factor (2.205×10^{-6}).

In summary, estimates of annual nitrogen loads leaving the site were obtained from summations of monthly loads estimated to cross each of the northern, eastern, and southern site boundaries. Loads crossing each site boundary in each month were calculated using the formula:

$$(A + B) \times C \times D \times E \times F = G \qquad (11)$$

where the variables were defined as:

A = annual volume of ground-water recharge, in liters, entering the site across the western boundary;

B = annual volume of ground-water recharge, in liters, entering the site from precipitation;

C = proportional percentage of ground water, in liters, estimated to discharge across a site boundary (from model output);

D = monthly fraction of annual discharge;

E = nitrate concentration of a sample (or of samples), in milligrams per liter, collected to characterize water quality;

F = milligram to pound conversion factor (2.205×10^{-6}); and

G = monthly nitrogen load, in pounds, discharged across a site boundary.

The loads of nitrogen discharged in ground water averaged 7,950 pounds per year in the 1985-86 prenutrient-management period, and averaged 7,925 pounds per year in the 1987-90 postnutrient-management period. Because loads are calculated by multiplying ground-water discharge by ground-water nitrate concentrations, average annual loads did not decline because ground-water discharge averaged about 6 inches per year more in the postnutrient-management period. However, if annual nitrogen loads are examined after normalizing for discharge as shown on table 7.5-18, a decrease in ground-water nitrogen discharge is apparent from the prenutrient-management to postnutrient-management periods.

Preliminary data analyses illustrated on figure 7.5-32 and table 7.5-19 indicate that reductions of the monthly nitrogen discharges in ground water are not due to dilution by increased ground-water discharge in the postnutrient management period, but represent a change in the relation between nitrogen discharge and ground-water discharge. For example, a monthly ground-water discharge of 4 inches contained

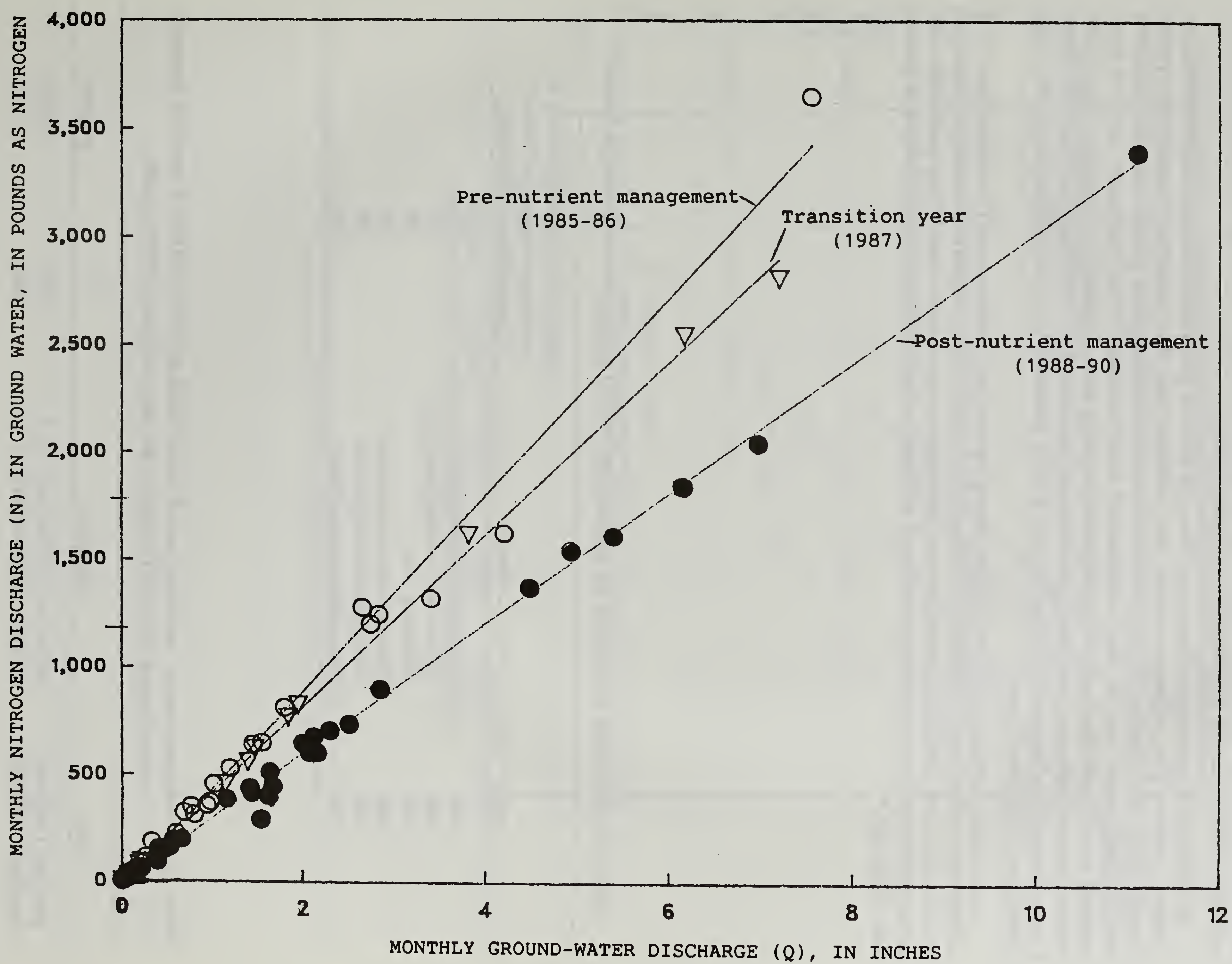


Figure 7.5-32.--Relation between monthly ground-water discharge and nitrogen discharge

approximately 1,750 pounds of nitrogen during the pre-BMP period, but only approximately 1,200 pounds of nitrogen during the post-BMP period. Reductions in loads of nitrogen discharged in ground water occurred during the postnutrient management period because reductions in fertilizer applications caused less nitrogen to be available for leaching to the ground water.

By entering the ground-water discharge values (Q) from the postnutrient management period into the equation defining the discharge-nitrogen load relation from the prenutrient-management period (N = 457,225 Q - 27.4), loads of nitrogen that would have been discharged in ground water from the site if nutrient management had not been implemented were predicted. When cumulative sums of these predicted monthly nitrogen loads in ground-water discharge were compared to cumulative sums of the measured monthly nitrogen loads using a double-mass procedure (fig. 7.5-33) (Searcy and Hardison, 1960), it was estimated that nitrogen discharge in ground water decreased by 11,048 pounds during the 4-year postnutrient management period.

In conclusion, virtually all of the nitrogen leaving the site, that is not consumed by crops or lost to the atmosphere by volatilization, is discharged in the ground water. Over 99 percent of the nitrogen discharged from the site in the surface and ground water is discharged in the ground water. Highly permeable soils, terraced hillslopes, and a grassed waterway may facilitate the rapid infiltration of precipitation to ground water at the site.

Table 7.5-18.--Loads of nitrogen (in pounds) per inch of ground-water discharge 1985-90

Year	Period	Nitrogen load in ground water, in pounds of nitrogen per inch of ground-water discharge
1985	Pre-nutrient management	421
1986	Pre-nutrient management	450
1987	Transition year	408
1988	Post-nutrient management	306
1989	Post-nutrient management	298
1990	Post-nutrient management	304

Table 7.5-19.--Regressions of monthly ground-water discharge (MGWD) and monthly ground-water nitrogen (MGWN) loads for the pre- and post-BMP periods

Period	Equation	R^2	p-value
Pre-BMP (1985-86)	MGWN = 457.23MGWD - 27.4	0.987	0.001
Post-BMP (1988-90)	MGWN = 303.09MGWD - 7.13	.996	.001

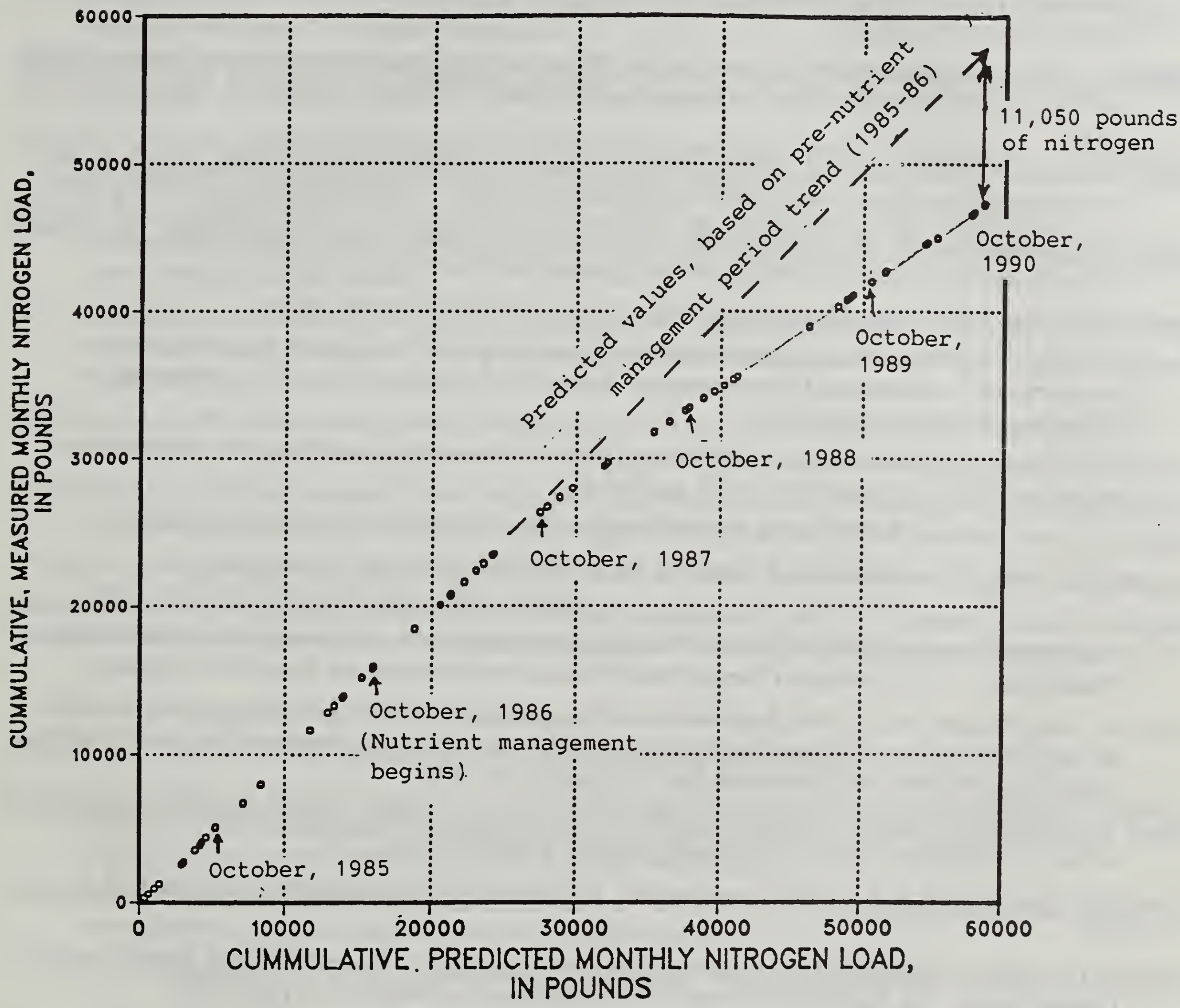


Figure 7.5-33.--Comparison of measured and predicted cumulative monthly loads of nitrogen for water years 1985-90.

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Summary of 1984-1990 Research in Lancaster County

R.H. Fox and J.D. Toth

The Chesapeake Bay Program provided us with the opportunity to expand our research designed to increase nitrogen fertilizer efficiency for PA farmers and to reduce nitrate pollution of the region's waters. A primary focus of our research program has been to develop easy-to-use tests that could tell whether there is enough nitrogen in the soil for high corn yields, and hopefully avoid applying excess nitrogen fertilizer that is unnecessary for attaining these yields. Excess nitrogen would not be used by the corn and is then free to move out of the soil into the groundwater, showing up in wells and water supplies, and eventually in the Bay. Lancaster County is an ideal place for this sort of work since it is prime farming country, and has a wide range of management types, including dairying, livestock operations and cash grain farms. Also, the people working for the Upper Conestoga Rural Clean Water Project were in close contact with local farmers and could help us find the sorts of fields best suited for our nitrogen testing studies.

Farmers have known for a long time that animal manures and rotations of corn with legume crops like alfalfa, clover and soybeans can provide nitrogen to a following corn crop. However, deciding exactly how much nitrogen is available from these sources has been difficult. A test for nitrogen taken in fall or early spring, like those commonly used for potash and phosphorus, was not possible since the amount of nitrogen in the soil in forms that can be used by corn can change rapidly and be lost easily when it is washed down through the soil by rainfall. The organic nitrogen in manure and legume crops can't be used by corn directly, but must first be broken down by the action of naturally-occurring soil bacteria into other forms of nitrogen, particularly nitrate-nitrogen. It appeared that a test for nitrate taken in late spring, developed at the University of Vermont, after warming weather causes a good deal of breakdown of the manure and crop residues and after the heavy spring rains that remove nitrogen from the soil have finished would also work in Pensylvania.

Our field experiments are of two basic types. One uses five rates of nitrogen fertilizer, from 0 to 179 lbs N per acre, applied to 25 plots each about 20 by 35 feet in size. We take soil samples before planting, at planting, at pre- sidedress time (the time of greatest demand for nitrogen by the growing corn crop), and on some fields after harvest and again the following spring. Plant sampling has included at various times stalk samples taken at sidedress time, leaf samples for plant nutrient analysis at silking, stalk samples again at harvest and harvest yield checks so we can see at what N rate the maximum yields and economic optimum yields were achieved. Other experiments are smaller versions of those described above, with three N rates applied to twelve plots, 0 and 179 lbs N per acre, and a third rate determined by the results of the most successful of our soil N tests, which is described below. Sampling on the second type of experiment is similar. We interview the farmers before planting to get a field history including manure applications and previous crops on the field, and keep in touch with them through the growing season. Reports on the results of our tests are sent to the farmers after the growing season. Farmers throughout the state have been very interested in our work, and have helped us greatly with their cooperation.

Initially, two tests seemed promising. Stalk samples taken just before sidedress time gave us good results for several years, but weather conditions and soil moisture around sampling time had a large effect on the nitrate content of the stalks, which were limitations that prevented its use as an accurate measure of nitrogen for the corn. However, testing 0-12 inch soil samples taken just before sidedressing which we called PSNT (Pre- sidedress Soil Nitrate Test), gave us very good results. We found that if there were over 21 to 25 parts-per-million (ppm) nitrate-nitrogen in the soil before sidedress time, in almost every case this was enough to guarantee maximum yields as determined by our harvest checks at the end of the season (Figure 1). If there was less than this amount of N in the soil, we could get a rough estimate of how much more N would be required for maximum yields. After using this test for several years in our research, we felt enough confidence in it to develop a simple version that could be used in the field. Our group and Dr. Doug Beegle of the Cooperative Extension came up with a test kit that was first used in the field statewide in 1989. County Extension and crop management services provided the test for farmers, and over 2700 fields were sampled using this PSNT test kit in 1989 and 1990. Early results have been very encouraging.

While the PSNT was designed originally for fields with limited amounts of N in the starter fertilizer and most N applied at sidedress times, we have found it works equally well for farmers who want to apply most of their nitrogen at planting (Figure 2). The same 25 ppm soil N level works for fertilizer applied at planting.

Although the PSNT has worked well on most fields, we have found several situations in which it does not do as good a job of predicting whether a corn field will need more nitrogen. Most of these are related to the need for a reasonable amount of manure or legume nitrogen to be broken down before the test is performed, which is generally about five weeks after planting. Conditions that favor cold, wet soil will slow the breakdown of organic nitrogen and the test will show nitrate levels to be low. The test results will then predict extra nitrogen is needed on that field, but harvest checks will show no higher yields on plots that received the extra nitrogen. No-til fields and poorly drained fields both can have soils that stay cold later in the season and have caused some problems for the test. These conditions are less important in Lancaster County than in northern and western PA, where the climate is cooler and more poorly drained fields are under cultivation.

In another of our tests we study the movement of nitrogen down through the soil by taking cores to four feet in fall after harvest and again the following spring using a tractor-mounted hydraulic sampler. These samples show that on some fields receiving yearly manure applications or which have high N fertilizer rates in addition to manure, the nitrate remaining in the soil after harvest and thus available to be lost to the groundwater can be above the suggested EPA limits for drinking water. For these fields, using the amount of nitrogen that will give economic optimum yields is especially important. Better manure management practices may also lessen the danger of nitrate pollution of groundwater.

We are looking at several other nitrogen tests that can give us a better understanding of the nitrogen status of a corn crop. One is a chlorophyll test using a hand-held light meter, in which the green color of the corn leaves can be used to estimate the amount of nitrogen in the plant, thus the nitrogen in the soil. In another test, soil sample extracts taken at planting or pre-sidedress are analyzed using UV light. This test may do a better job than the PSNT at estimating the amount of fertilizer required on fields that will benefit from added nitrogen. Finally, we confirmed the finding in Iowa that the content of nitrate in the lower portion of the corn stalk is a reflection of the amount of nitrate in the soil. Sampling the stalks at harvest can tell you if there is excess nitrogen present at the end of the growing season and provide a check on the accuracy of the PSNT.

Project Title:	Application of an on-farm monitoring and measurement system in the management of farm nutrients.
Project Leader:	Les E. Lanyon, Associate Professor of Soil Fertility, Department of Agronomy, The Pennsylvania State University, University Park, PA 16802
Date:	February 27, 1991
Project Objective:	To demonstrate the use of nutrient management record keeping and on-farm scales in the implementation of nutrient management BMPs for the RCWP area.

Project Summary:

The project was active on a total of four farms, two dairy farms and two intensive crop and livestock farms, in the Conestoga Headwaters RCWP area. On these farms the material flow of manure, crops, feed, fertilizer, animals and animal products was measured. The measurements were used to calculate nutrient balances for individual fields, individual livestock enterprises and for the entire farms. These balances were compared to expected nutrient management performance standards based on nutrient balance concepts. Results of the activity monitoring were used as the basis for possible revisions of nutrient flow on the participating farms. Not only did the activities form the basis of the performance assessment and they also served as reference points when changes in nutrient flow were considered.

Nutrient flow measurement and monitoring indicated that in some cases considerably more nutrients are brought onto the farms in feed and other livestock supplies than in fertilizer. Therefore, fertilizer management on a field-by-field basis will not adequately address the real nutrient management issues of farms in this intensive agricultural area. The off-farm transport of manure either to the fields of other farmers or to rented fields was found to be effective in managing excess manure on one of the farms.

Comparisons of nutrient management plans prepared for the farmers with the the actual farmer activities indicated that farm-to-farm differences between the plans and the actual implementation activities were common. The deviations from the plans were generally based on lack of sensitivity of the plan to actual farm activities. These actual activities resulted in less manure produced than predicted, or greater yields, or crops with greater nutrient utilization than projected in the planning process. Even though the plan may not have been followed exactly as it was written, farmers were able to farm within satisfactory performance levels as determined by the nutrient balance assessments.

The on-farm scales, manure and crop analysis programs, and record keeping of farm information were essential to the estimation of nutrient management performance. Nutrient management plans by themselves were not adequate to determine how nutrients were being applied or used on farms in the area. Estimates of manure spreader contents and the amount of crops produced were often incorrectly estimated. We measured some differences between farmer estimates and actual weights of almost+70%. The record keeping system was essential for the collection and subsequent use of the observation of farm material flow in the assessment of farm performance in protecting water quality.

Farm nutrient management plans by themselves are inadequate to certify the nutrient management performance of farms either to the farmer or for society. The plans must become part of a nutrient management process that is governed by a strategy of farming within the constraints of nutrient management to protect water quality. This strategy will require reinforcement throughout the agricultural production system, new practices such as on farm monitoring and information management capabilities, and community support to cope with the implications of the new management strategy.

BIOCHEMISTRY OF NITROGEN FROM DAIRY CATTLE MANURE AND THE CYCLING EFFECTS OF CARBON AND NITROGEN ON NITRATE LEACHING FROM SOILS

Dale E. Baker, Leon E. Marshall, Mary K. Amistadi, Karen Simmons, Carol S. Baker, James Phillips, Erik Lotse, and Joseph Senft

SUMMARY OF FINDINGS AND PROPOSED PROGRAM

1. Identification of the water or water-related problem.

Technology developments for dairy farming have resulted in high animal numbers concentrated on the more productive lands in Karst regions of Pennsylvania. With the increase in efficiency of milk production, the production of manure has reached levels of 2 or more times the amounts required to provide the nitrogen and phosphorus requirements of the crops harvested on most of these farms. While phosphorus increased greatly within the soils, much of the excess nitrogen was lost via leaching of nitrates. Legislation has been introduced to require that the management of these lands be changed to prevent nitrate-N leaching. However, our present knowledge of the relationship between nitrogen management and water quality is inadequate as a base for land management decisions.

2. Contribution to problem solution

It is proposed that waste sources of carbon can be introduced into these systems to increase nitrogen immobilization as a means of decreasing the leaching of nitrates across the boundary of the plant root zone. The carbon sources may be spread directly on the fields, used as bedding, or introduced into existing manure storage structures. It is postulated that this change in management, complemented by an expected decrease in land values as a result of pending legislation, will enable economically sustainable and environmentally compatible dairy farming in this region.

3. Objectives

a. To develop methods to measure the biologically available nitrogen and carbon in soils on dairy farms in Lancaster County, Pennsylvania, and incorporate the results into existing models for predicting nitrate leaching into groundwater.

b. To evaluate the effects of carbon amendments from external sources on (i) the nitrate-N remaining in the root zone at the end and beginning of each growing season using soil core samples and (ii) the concentrations of nitrate-N in water moving across the plant root boundary at a depth of 1.2 meters over time.

4. Approach

While the technology and equipment required for the field experimentation is in place, the management system(s) and monitoring method(s) proposed for development will be required to enable farmers to take advantage of the benefits to be derived from the use of carbonaceous wastes. In addition, the existing LEACHM model will require modification and evaluations of additional soil and climatic parameters. It is proposed that the diagnostic approach to soil testing based on the physical chemistry of solutions which has been used on thousands of soils to monitor the availability of metals be extended to include the bioavailability of C and N with the results being added to an appropriate model for predicting crop production and nitrate leaching. The model developed in Sweden shows promise.

5. Result users

Dairy farmers, extension personnel, adult education leaders, U.S.G.S. personnel, farmers and others have been working together on this problem for several years. Rapid adoption of recommended changes by farmers and related industries is anticipated.

Biochemistry of nitrogen from dairy cattle manure and the cycling effects of carbon and nitrogen on nitrate leaching from soils

The research has continued to build upon existing data and experience on soils with dual pore systems on farms in Lancaster County, Pennsylvania, where nitrate pollution of groundwater from excessive applications of manure is prevalent. The overall goal of the research has been to establish to quantify the biologically available nitrogen status of these soils in order to prevent excessive leaching of nitrates across the plant root boundary. The hypothesis to be tested next is that by use of supplemental carbon sources that are controlled with respect to concentrations of metals, the soil productivity may be maintained and perhaps enhanced at the same time that the nitrogen now leaching as nitrates is converted into immobilized nitrogen within the soil. The specific objectives include:

a. To develop methods to measure the release of biologically available nitrogen and carbon in soils on dairy farms in Lancaster County, Pennsylvania, and incorporate the results into existing models for predicting nitrate leaching. The method(s) will be based on bacterial growth determinations using selected Pseudomonas strains adapted to soil culture combined with the incorporation of historically important concepts relating colloid chemistry, the chemistry of humic substances, and the physical chemistry of solutions as developed for ions by Baker and Low (1970), Baker (1971 and 1973), and Baker and Amacher (1981).

b. To evaluate the effects of carbon amendments from various external sources on the movement of nitrate-N across the root boundary and the residual nitrate-N remaining in soil at the beginning and end of the growing season to a depth of 1.2 meters (4 feet). Nitrate-N within the soil at the end of the growing season will be modeled as a function of the biologically available nitrogen and carbon within the soil at various depths. The carbon sources will include conventional crop residues, recycled paper, paper rejects and sludges from paper mills, paper char, yard wastes and municipal refuse. The off-farm carbon sources will be analyzed chemically and biologically for the presence of toxic chemicals before they are applied to field soils, and only organic carbon-containing materials with metal concentrations at or below those typical of soils will be included.

The results of the proposed research will form the basis for nitrogen monitoring and land management of manure and carbon sources to decrease nitrate pollution of groundwater.

Background information and related ongoing research:

The project leader has been conducting research in Lancaster and other counties of Southeastern Pennsylvania for several years as a part of the Rural Clean Water Program (Robinson, Anderson, and Baker, 1983; Unangst, 1989) and as a part of the Pennsylvania Chesapeake Bay Program (Baker, 1986). Dr. Baker served as one of a 10-member select committee to make recommendations to the Governor of Pennsylvania regarding the need for legislation to regulate land use for water quality. The proposed regulations will require combinations of practices and alterations of existing operations to meet the imposed water quality criteria. The management program to be developed as a part of this proposal and other on-going research will be required to maintain the dairy industry within the Commonwealth. The proposed requirement that all operations must immediately meet water quality criteria will likely result in a reduction in farm land prices from the current $7,000 - $14,000 per acre. Some dairy farms may have to increase acres or decrease animal units in order to meet water quality criteria. However, over the next 5 to 10 years, the supply of low cost, readily available waste carbon may enable changes in soil management to substantially reduce groundwater pollution with nitrates. Currently dairy farmers are finding it necessary to treat their well water to remove nitrates to prevent infertility and related cattle health problems.

Ongoing projects related to the proposed effort:

A five year research project supported by the Pennsylvania Chesapeake Bay and Rural Clean Water programs was completed in 1989. These data have been summarized in a Ph.D. thesis by Karen Simmons (1990). The goal was to combine the corn growth model CERES-Maize to predict corn grain and silage yields on these soils as affected by past and present treatments with respect to N. It was found that no crop response was obtained from N additions for the first 3 years of corn following alfalfa. In the 4th year a small

but significant yield response was obtained from starter fertilizer N. Because of the high levels of residual, available N, which can not now be measured. the CERES-Maize model predicted responses to applied manure and fertilizer N when none were obtained.

A research project supported in part by U.S.G.S. funding is near completion. Using the experimental plots of Simmons (1990), we have shown that nitrate pollution of groundwater in this region of Pennsylvania is not the result of rapid leaching of nitrates resulting from rapid infiltration of water via macro-pores or cracks which are common in the soils of the region. Instead, the data from several years of monitoring soils with depth in the fall and spring and more detailed studies of the hydrology and results of infiltration studies indicate that much of the groundwater recharge for this region results from macro-pore flow during the late fall, winter and spring while the soil is at or above field capacity. As a result of rapid infiltration and movement of water via macropores or channel flow plus a relatively slow percolation of water held in micropores, only 50% of the nitrates held within soil profiles at the end of the growing season is leached across the bottom of the plant root boundary at the 1.2 m depth. (Baker, 1986; Baker and Rogowski, 1987; and Baker, 1988).

Models currently used to predict leaching of nitrate-N have shown that nitrate-N leaching is poorly predicted. (Lotse et al., 1990). The poor prediction results from an inability to predict nitrogen release from residual, available N which has accumulated within soil profiles as a result of excessive applications of manure N over the past 20+ years. At this time it is predicted that the LEACHM model of Wagenet and Hutson (1989), with incorporation of climatic data relating to N mineralization and nitrification from the model of investigators in Sweden (Johnson et al., 1987) should be able to rapidly include other ongoing research and that proposed here to complete the model so greatly needed for areas with very high rates of manures and high amounts of residual, available N.

An ongoing research program supported by U.S.D.A. - C.S.R.S. involves the identification of important nitrogen-containing organic compounds associated with the residual, available N within these soils. Currently, experimental plots from 9 corn fields on 8 different farms are being harvested, and the soils from each field plot are being sampled to a depth of 1.2 m. The soils will be analyzed for inorganic N to determine differences among fields and the effect of soil incorporation of saw-dust on the amount of inorganic and organic N remaining in each soil profile. Some of these fields will be selected for the proposed research.

It seems clear at this time, based on the data from these projects and the extensive field surveys reported by Baker (1986 and 1988) that the pollution of groundwater with nitrates in this region is the result of the following factors:

1. Excessive animal units per acre resulting from a combination of highly productive soils (corn grain yields of 200 to 235 bushels per acre are common); dedicated farm managers; liquid manure storage facilities; and relatively low grain prices from other counties and other states.
2. Lower C:N ratios of applied manure resulting from management systems with less bedding (straw, shavings, etc.) than was used prior to the incorporation of liquid manure storage structures.
3. Lower losses of manure N resulting from more timely spreading and incorporation of the manure held in storage structures.

Lancaster County, which has only 5% of the total land in farms in Pennsylvania, has 15.5% of the dairy cows, 38.5% of the swine, 14% of the beef animals, 39% of the broilers, 48.75% of the laying hens and 5.8% of the sheep in all of Pennsylvania (Baker and Crider, 1989). When the surrounding counties in Southeastern Pennsylvania are included, it becomes obvious that reductions in animal units per acre and/or exporting of manures from the region are not presently viable alternatives for an economically sustainable and environmentally compatible agriculture in Pennsylvania.

Since it will probably be less economical for dairy farmers to market their wastes than for swine and poultry operations that are closely affiliated with large feed companies, an alternative for the county and other areas with soils derived from limestone bedrock could involve the incorporation of more carbonaceous materials into the soils to reduce the rate of nitrogen mineralization. While this alternative is not considered a sole long-term solution for the region, it offers the only low cost, environmentally compatible alternative for dairy farmers. However, a method has not been developed to monitor active,

available organic carbon and nitrogen compounds as they related to microbial cycling, crop N requirements, and fertilizer N management to improve N efficiency, maintain or increase crop yields and minimize water quality degradation.

The data on carbon and nitrogen relating to net mineralization of N must then be combined with the climatic data and data on soil properties including other nutrients and air- water relations for different locations. We have found no evidence in the literature for an integrated process or protocol which relates to systems management and which incorporates the components of existing technology into models for field corn production plus the use of carbonaceous wastes to improve soils by beneficially increasing soil organic matter, while simultaneously decreasing the leaching of nitrates. Although objective 1 is considered an essential component of the required management program, it is not considered appropriate to strive for the development of this practice without its incorporation into an integrated field corn management and environmental quality "leaching" model to account for groundwater pollution with nitrates.

The question to be answered is "Can a model from climatic data, bioassays and chemical analyses of field soils predict the over-all effect of the mineralization-immobilization processes on net mineralization over a growing season?" Net N mineralization in the fields to be studied will be affected by variable rates of manures and carbon sources. Without the experience gained over time with measurements of ion availability as affected by sewage sludge applications on lands in Pennsylvania and studies over the past 10 years on fields in Lancaster County, one would not attempt to answer the question in the affirmative.

Economically sustainable and environmentally compatible dairy herd management systems in the region and other locations with high animal densities will require that manure N be used to supply N required by crops, which are mostly corn for grain and silage. However, this practice has been operational for enough years on most farms of the region to bring phosphate levels into the range which causes undesirable pollution of surface water (Baker, 1988; Baker, McMackin and Wolf, 1988). However, if the nitrate pollution problem could be solved, the phosphorus levels in the surface soil could be reduced by deep tillage. Deeper incorporation of phosphorus and organic matter could increase crop yield potentials especially in seasons with deficient moisture. The plant availability data of Simmons (1990) indicate that the organic matter of the surface soils should be as high as 8% to have all of the N within the profile in the form of stable soil organic matter at a C:N ratio of 10:1. The goal of the proposed research is to reduce the bioavailability of manure N to the extent required to help dairy farmers to apply their manure to the appropriate corn crops to maintain and perhaps increase yields without excessive leaching of nitrate-N to groundwater.

Theoretical considerations for the management system(s):

In contrast to the traditional approach in which the availability of organic C and N are a function of their total concentration, the hypothesis for new management strategies is that the existing concepts for the Diagnostic Approach to Soil Testing (now known as the Baker Soil Test TM) based on the principle of small exchange can be made applicable to nitrogen and carbon in soils. Instead of extracting soils with strong acids and bases, the equilibrating solution developed by Baker (1971) with modifications to be developed as a part of this research will be used to remove a small, constant, active fraction of the organic nitrogen and carbon compounds as well as inorganic nitrogen. It is anticipated that the organic compounds found in solution will reflect a constant, active fraction of the bioavailable organic carbon and nitrogen which can be measured directly and indirectly in the laboratory.

Soils are three phase systems (solid, liquid and gas). The solid phase consists of numerous components, which makes the application of the phase rule in physical chemistry very difficult. Operationally, however, the concept can be useful. For nitrogen, as for metallic ions, the availability to plants will be determined by the component of the solid phase that determines the activity of the NO_3^- and NH_4^+ ions in the soil solution. In the case of organic N and C, it is postulated from theory and experience that the activities of the plant available forms within a given soil and climate will be more highly correlated with the ionic forms plus the carbon, nitrogen and C:N ratio of the material removed by an appropriate small exchange to shift the equilibrium to render a constant, quantitatively measurable fraction of residual, microbial available C and N into the soil solution. If the free energy of the components remains equal in both the liquid and solid

phases, then it follows that "equal amounts of a given substance (N, C, etc.) must have exactly the same free energy in two phases at equilibrium" (Glasstone, 1957, pg. 251). In equation form the small exchange may be written for solid, a, and solution, b, as

$$\overline{G}_a - d\overline{G}_a = \overline{G}_b + d\overline{G}_b \quad (1)$$

where $\overline{G}$ is the relative partial molar free energy of the component. If the quantity of material in the solid phase is very large as has been found for these soils, the change in free energy imposed on the solid phase will be negligible and the relationship for 1 will not change the initial equilibria, i.e.

$$\overline{G}_a = \overline{G}_b \quad (2)$$

Since soil profiles in Lancaster County have been found to contain up to 10,000 pounds of residual manure nitrogen per acre, it should be possible to remove 100 to 200 ppm of N with compounds representative of the residual, available N in soils without changing the free energy relationships of the carbon and nitrogen associated with the residual, available soil N.

For ionic equilibria in soils, this relationship has been used in Pennsylvania to protect land from undesirable increases in the availability of heavy metals from sewage sludges for the past 15 years (Baker, 1971, 1973, 1974, 1976a & b, 1977a & b; Baker and Amacher, 1981; Baker, et al., 1985; and Baker and Bowers, 1988).

The concept of small exchange applied to organic compounds:

The diagnostic approach to soil testing evolved from the concepts of the ratio law (Schofield, 1947; Schofield and Taylor, 1955; Woodruff, 1955) and the Vanselow equation for cation exchange (Vanselow, 1932). Vanselow related the activity of an ion in a soil suspension to its mole fraction on the exchanger and Woodruff's "energy of exchange" related ion uptake by plants to the difference in chemical potentials of two ions (Ca and K) in soils. When the two approaches and the available data from field experiments were considered together using simultaneous equations, the soil solid phase parameters dropped out, leaving the solution chemistry as the component that determines ion availability. The approach for organic carbon and nitrogen is not expected to be as straight forward as has been verified for macro-cations (Baker, 1971) or for metals (Baker, 1973, and Baker and Amacher, 1981). However, if one visualizes the soil-water system at moisture levels between field capacity and the wilting point, the plant roots within the water film surrounding the roots as well as the soil solid phase may be in a solution that is in dynamic equilibria with organic compounds as well as the inorganic ions which have been evaluated by the diagnostic approach. The question to be answered from initial experiments is "will the equilibrating solution containing 5 mmole $CaCl_2$, 1 mmole $MgCl_2$, and 0.25 mmole KCl render a small exchange of both the inorganic ions and the yet undefined organic compounds considered in equations 1 and 2, above?"

Major nitrogenous materials identified in soils and the significance of the biologically relevant C:N ratio:

The predominant organic nitrogenous materials identified in soils include amino acids, peptides and proteins (20-50%) combined amino sugars (10- 20%) and the purine/pyrimidine components of nucleic acids (1-7%). All of these compounds can serve as precursors of the inorganic N formed by microbial action in soils. Clearly, certain amino acids and amides present in humus are effective precursors since their levels fall during mineralization (Alexander, 1961a). The water soluble nitrogen fraction of plant materials undergoing decomposition is that portion capable of most rapid conversion to ammonia, and this fraction is rich in amino acids and hexosamine nitrogen. The remaining unidentified nitrogenous compounds (20-50%) are not believed to contribute greatly in the short term (one or two growing seasons) to the problem of nitrate production because these polymeric forms are only slowly broken down to mineralized N.

Alexander (1961a) has defined the net change in the amount of inorganic N, N_i, to be:

$$N_i = \text{Organic N mineralized} - (N_a + N_c + N_l + N_d), \quad (3)$$

where N_a = nitrogen assimilated by soil microorganisms
N_c = nitrogen required by the crop
N_l = nitrogen lost through leaching, and
N_d = nitrogen lost through denitrification.

Of these factors, the amount of nitrogen assimilated by soil organisms can vary markedly and is influenced by the organic carbon content of the soil. In largely untreated soils, organic carbon and nitrogen are mineralized in parallel and the ratio of CO_2 to N_i produced falls within the range of 7 to 15:1. The lower ratio is generally seen in microflora producing nitrate, an indication that microbial energy is derived from the oxidation of fixed carbon to form CO_2. As expected, this equilibrium can be disturbed by external factors, and introduction into the soil of highly nitrogenous materials favors N_i and an even lower CO_2:N_i production ratio. In such a situation, this is subject to nitrification and subsequent leaching as nitrate unless there is a corresponding need for N_i by the crop or unless there is sufficient available carbon to stimulate microbial biomass accumulation (N immobilization).

Roughly 5 to 10% of all organic N in the plow layer is in the form of amino sugars (Stevenson, 1983). Virtually all of this material is made up of glucosamine and galactosamine, with their C:N ratio being from 2:1 to 6:1, depending on the soil. Simple polymers consisting of hexosamine (or its acetylated derivatives, e.g. chitin), have a C:N ratio of 5:1 but because most hexosamine is found in combination with other sugars, the ratio is usually more like 12:1.

Stanford and Demar (1969) found in their studies on the extractability of nitrogenous substances from soil, that autoclaving of samples with dilute $CACl_2$ brought out 20% of the total organic N in several soil types and nitrogen contents. They further reported that the fraction consisted mainly of amino sugars which gave the highest correlation with nitrogen mineralized by these soils.

Nucleic acids have been a much unappreciated component of soils. While several reports indicate these materials comprise only about 1% of the organic N in soils, others have found as much as 7% of the soil N (18% of the N in the fulvic acid fraction) is present as either purine or pyrimidine compounds (Cortez and Schnitzer, 1979). Moreover, such compounds make up a major portion of the microbial biomass. Approximately 50% of the dry weight of most bacteria is due to nucleic acid. This material is very nitrogen-rich, having a C:N ratio of 2 or less. While there seems to be only limited documentation of this point, it would seem that the high quanine + cytosine content of soil nucleic acid points to microbial rather than plant origin. For soils receiving excessive manure N over long periods of time as has been found for soils of this proposed investigation, the nucleic acids could well be a major source of mineralizable N in these soils that should be converted to immobilized N.

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APPENDIX D.--QUALITY ASSURANCE

A laboratory quality-assurance plan was developed for the project with the PaDER, Bureau of Laboratories where the nutrient and pesticide analysis of water-quality samples were performed.

Several types of samples were used to evaluate the quality of data. Blank samples of distilled water were routinely submitted for analysis. These samples evaluated the laboratory baseline capabilities at near detection limit levels. Standard USEPA and USGS reference water-quality samples were submitted for analysis on a routine basis. These samples were used to determine laboratory accuracy. Duplicate water-quality samples were split in the field and also submitted to the PaDER, Bureau of Laboratories for analysis. This third sample type measured the laboratory repeatability of the individual constituents.

The Wilcoxon two-sample (Mann-Whitney rank sum) test and the Wilcoxon signed rank (or one-sample) test, both standard statistical procedures, were used to evaluate the quality of the nutrient water-quality data. Quality-assurance data were collected throughout the monitoring period and checked frequently to assure a high quality of performance at the laboratory.

Concentrations of nutrients in blank samples should be near detection limits to constitute acceptable laboratory results. The statistical comparison of this data first required the calculation of the difference between reported values and the detection limits for each constituent in each sample. The difference should be approximately equal to zero. A signed-rank test was performed on the difference to test this hypothesis. The results indicated that the means of the calculated concentrations were statistically different from the detection limit for total and dissolved ammonia and total and dissolved organic plus ammonia nitrogen. This could indicate either a positive bias for reported levels near detection limits, or less than pure distilled-water blanks.

Standard-reference samples were analyzed for total and dissolved ammonia, ammonia plus organic nitrogen, nitrate-nitrogen, and phosphorus. Evaluation of the signed-rank test results showed a statistically measurable difference between the measured and known values for dissolved nitrate, total and dissolved ammonia plus organic nitrogen, and total and dissolved ammonia at the 95 percent confidence level. Except for total and dissolved ammonia plus organic nitrogen, the median difference between the known and reported values was 0.01 mg/L or less. The reported values for all other constituents did not differ significantly from their known values at a 95-percent confidence level.

The duplicate data were evaluated by use of the Wilcoxon two-sample test which compared the data as two independent groups. No statistically measurable difference was detected between groups for any constituent, indicating that there was good repeatability in laboratory analysis.

The quality of the nutrient water-quality data has been evaluated with several statistical procedures and sample types. The results of this evaluation, summarized in table D-1, indicate that there was an acceptable degree of repeatability by the laboratory for the analyzed nutrient constituents. The analyses were found to be accurate for most constituents. Total ammonia plus organic nitrogen and total phosphorus exhibited some error probably because of limitations of analysis techniques. Although more error was associated with these characteristics near detection limits, the actual samples rarely had concentrations near detection limits.

Samples from storm events at Stations 3 and 5 in the Small Watershed were periodically collected by hand to compare with samples collected by the automatic-pumping samplers to insure that the automatic samples were representative of stream-water quality. Thirty-five samples were collected for comparison between July 1984 and February 1989. A statistical comparison using both parametric and nonparametric techniques (T-test, Wilcoxon signed-rank test, and Sign test) of the nutrient concentrations for these samples showed no significant difference between corresponding sample pairs.

The PaDER, Bureau of Laboratory, followed the prescribed quality assurance procedures discussed in Quality Assurance Handbook (1988), and the U.S. Geological Survey laboratory followed procedures described by Friedman and Erdmann (1982) and Jones (written commun., 1991).

Table D-1.--Summary statistics for quality assurance analysis

[Detection limits, ranges, and median differences in mg/L as N or P;
n, number of samples; Min, minimum; Max, maximum; <, less than; --, no data]

Constituent	Detection limit	n	Concentration range		Blanks				Standards						Duplicates					
					n	Range of reported values		Median difference from detection limit	n	Range of known values		Difference between known and reported values			n	Concentration range		Difference between pairs		
			Min	Max		Min	Max			Min	Max	Min	Max	Median		Min	Max	Min	Max	Median
Total $NO_3 + NO_2$	0.04	1,507	<.04	19	32	<0.04	all	0.00	--	--	--	--	--	--	80	1.0	57	-4.5	3.1	0
Dissolved $NO_3 + NO_2$	.04	598	.12	14	30	<.04	.08	.00	--	--	--	--	--	--	200	.96	115	-9.6	10	0
Total NO_2	.01	1,460	<.01	2.6	29	<.01	.02	.00	--	--	--	--	--	--	80	<.01	2.7	-.40	.07	0
Dissolved NO_2	.01	597	<.01	1.5	29	<.01	.01	.00	--	--	--	--	--	--	93	<.01	.44	-.07	.04	0
Total NO_3	--	--	--	--	--	--	--	--	62	.14	17	-2.6	1.4	0.02	--	--	--	--	--	--
Dissolved NO_3	--	--	--	--	--	--	--	--	25	.14	17	0	1.0	.03	--	--	--	--	--	--
Total NH_3 + organic	.20	1,505	<.20	37	31	<.02	1.0	.10	54	.33	21	-7.7	5.7	.51	79	<.20	22	-4.1	1.1	0
Dissolved NH_3 + organic	.20	594	<.20	15	29	<.20	1.0	.07	26	.66	16	-3.9	2.6	.50	191	<.20	9.2	-.50	.54	0
Total NH_3	.02	1,458	<.02	10	31	<.20	.11	.02	52	<.02	23	-4.0	.50	.00	80	<.02	10	-.20	.57	0
Dissolved NH_3	.02	597	<.02	7.9	29	<.02	.13	.03	25	.28	23	-2.5	.30	.05	93	<.02	.45	-.10	.10	0
Total P	.02	1,506	<.02	24	31	<.02	.06	.00	70	<.02	4.7	-1.7	3.5	.02	91	<.02	25	-.10	.19	0
Dissolved P	.02	598	<.02	4.5	28	<.02	.05	.00	26	.20	3.5	-.24	.60	.1	83	<.02	4.3	-5.6	.11	0

[1] Difference between pairs was determined by subtracting concentration value for blind duplicate from concentration value for sample.

Conestoga Headwaters RCWP Monitoring Stations

[°, degree; ', minute; ", second; --, data not in storet]

Station	Storet number	Latitude	Longitude
	COMPONENT 1 - REGIONAL STUDY AREA		
Surface Water			
Little Conestoga Creek	01576085	40°08'41"	75°59'20"
Conestoga River	01576105	40°08'44"	76°04'41"
Muddy Creek	01576240	40°10'12"	76°06'21"
Cocalico Creek	01576330	40°11'39"	76°09'09"
Groundwater			
	BERKS COUNTY		
Well BE 1401	401645076030301	40°16'45"	76°03'03"
Well BE 1402	400851075530801	40°08'51"	75°53'08"
Well BE 1403	401025075510101	40°10'25"	75°51'01"
Well BE 1404	401012075552901	40°10'12"	75°55'29"
Well BE 1405	400913075522301	40°09'13"	75°52'23"
Well BE 1406	400925075512201	40°09'25"	75°51'22"
Well BE 1407	401648075045901	40°16'48"	75°04'59"
Well BE 1408	401408076011001	40°14'08"	76°01'10"
Well BE 1409	401259075570201	40°12'59"	75°57'02"
Well BE 1410	401803076071101	40°18'03"	76°07'11"
	LANCASTER COUNTY		
Well LN 1441	401135075585101	40°11'35"	75°58'51"
Well LN 1442	400850075572101	40°08'50"	75°57'21"
Well LN 1446	401338076110701	40°13'38"	76°11'07"
Well LN 1465	401142076054701	40°11'42"	76°05'47"
Well LN 1496	401318076085901	40°13'18"	76°08'59"
Well LN 1541	400715076015501	40°07'15"	76°01'55"
Well LN 1543	400758075574901	40°07'58"	75°57'49"
Well LN 1544	400834075541601	40°08'34"	75°54'16"
Well LN 1545	400920075561301	40°09'20"	75°56'13"
Well LN 1546	400637076053201	40°06'37"	76°05'32"
Well LN 1547	400658076063701	40°06'58"	76°06'37"
Well LN 1548	400725076062201	40°07'25"	76°06'22"
Well LN 1549	400759076015401	40°07'59"	76°01'54"
Well LN 1550	400938076072801	40°09'38"	76°07'28"
Well LN 1551	400808076062401	40°08'08"	76°06'24"
Well LN 1552	400833076023601	40°08'33"	76°02'36"
Well LN 1553	400627076013501	40°06'27"	76°01'35"
Well LN 1554	400628076011301	40°06'28"	76°01'13"
Well LN 1555	400608076012801	40°06'08"	76°01'28"
Well LN 1557	400828075561601	40°08'28"	75°56'16"
Well LN 1558	400826075564601	40°08'26"	75°56'46"
Well LN 1559	400855076085701	40°08'55"	76°08'57"

Conestoga Headwaters RCWP Monitoring Stations—Continued

Station	Storet number	Latitude	Longitude
Groundwater--Continued			
	LANCASTER COUNTY–Continued		
Well LN 1560	400932076092501	40°09'32"	76°09'25"
Well LN 1562	400927076080101	40°09'27"	76°08'01"
Well LN 1563	400813076081901	40°08'13"	76°08'19"
Well LN 1565	401127076094901	40°11'27"	76°09'49"
Well LN 1566	401152076101201	40°11'52"	76°10'12"
Well LN 1568	401135076072701	40°11'35"	76°07'27"
Well LN 1569	401457076073901	40°14'57"	76°07'39"
Well LN 1570	401032076073901	40°10'32"	76°07'39"
Well LN 1571	401157076082701	40°11'57"	76°08'27"
Well LN 1572	400734076001501	40°07'34"	76°00'15"
Well LN 1573	400918076013001	40°09'18"	76°01'30"
Well LN 1574	401215076115401	40°12'15"	76°11'54"
Well LN 1575	401016076000501	40°10'16"	76°00'05"
Well LN 1576	401114076013401	40°11'14"	76°01'34"
Well LN 1577	401240076005301	40°12'40"	76°00'53"
Well LN 1578	401436076045101	40°14'36"	76°04'51"
Well LN 1579	400906076001801	40°09'06"	76°00'18"
Well LN 1580	400730076051601	40°07'30"	76°05'16"
Well LN 1581	400727076035601	40°07'27"	76°03'56"
Well LN 1582	400606076003301	40°06'06"	76°00'33"
Well LN 1583	400712076004501	40°07'12"	76°00'45"
Well LN 1584	400847075593501	40°08'47"	75°59'35"
Well LN 1585	400823075584801	40°08'23"	75°58'48"
Well LN 1586	400853075552101	40°08'53"	75°55'21"
Well LN 1588	400644075585701	40°06'44"	75°58'57"
Well LN 1589	400648075583801	40°06'48"	75°58'38"
Well LN 1590	400744075565601	40°07'44"	75°56'56"
Well LN 1623	400757075553801	40°07'57"	75°55'38"
Well LN 1625	400954076093501	40°09'54"	76°09'35"
Well LN 1626	400830076044601	40°08'30"	76°04'46"
Well LN 1627	400809075540601	40°08'09"	75°54'06"
Well LN 1628	400810075592801	40°08'10"	75°59'28"
Well LN 1629	400702075595001	40°07'02"	75°59'50"
Well LN 1630	400708075582801	40°07'08"	75°58'28"
Well LN 1631	400603075580401	40°06'03"	75°58'04"
Well LN 1632	400608075582701	40°06'08"	75°58'27"
Well LN 1633	401708076080401	40°17'08"	76°08'04"
Well LN 1634	401620076113301	40°16'20"	76°11'33"
Well LN 1635	401109076034201	40°11'09"	76°03'42"
Well LN 1636	400848076065301	40°08'48"	76°06'53"
Well LN 1637	400943076055301	40°09'43"	76°05'53"
Well LN 1638	400959076051001	40°09'59"	76°05'10"
Well LN 1639	400834076033001	40°08'34"	76°03'30"
Well LN 1640	400858076024801	40°08'58"	76°02'48"
Well LN 1641	400809076001601	40°08'09"	76°00'16"
Spring LN SP 58	400744076583901	40°07'44"	76°58'39"

Conestoga Headwaters RCWP Monitoring Stations–*Continued*

Station	Storet number	Latitude	Longitude
Precipitation			
Martindale	–	40°09'22"	76°06'22"
Morgantown	–	40°08'27"	75°56'12"
Churchtown	–	40°07'41"	75°58'50"
Fisheries			
Little Conestoga Creek	–	40°08'41"	75°59'20"
Conestoga River	–	40°08'44"	76°04'41"
Muddy Creek	–	40°10'12"	76°06'21"
Cocalico Creek	–	40°12'14"	76°08'09"
Benthic-macroinvertebrate			
Conestoga River	–	40°09'42"	75°52'53"
Little Conestoga Creek	–	40°09'22"	75°55'14"
Little Conestoga Creek	–	40°08'47"	75°55'37"
Unnamed tributary to Little Conestoga Creek	–	40°08'20"	75°58'14"
Conestoga River	–	40°08'39"	76°00'37"
Conestoga River	–	40°08'42"	76°04'50"
Muddy Creek	–	40°12'37"	76°01'12"
Muddy Creek	–	40°10'16"	76°06'22"
Cocalico Creek	–	40°16'42"	76°12'17"
Cocalico Creek	–	40°12'14"	76°08'09"
COMPONENT 2 - SMALL WATERSHED			
Surface Water			
Little Conestoga Creek	015760831	40°09'22"	75°55'14"
Little Conestoga Creek	015760832	40°09'06"	75°55'05"
Little Conestoga Creek	0157608325	40°08'58"	75°55'06"
Little Conestoga Creek	015760833	40°08'50"	75°55'24"
Little Conestoga Creek	0157608335	40°08'47"	75°55'37"
Unnamed tributary to Little Conestoga Creek	01576089	40°08'20"	75°58'14"
Little Conestoga Creek	01576085	40°08'41"	75°59'20"
Groundwater			
Well LN1586	400853075552101	40°08'53"	75°55'21"
Well LN1662	400910075554401	40°09'10"	75°55'44"
Well LN1663	400843075552701	40°08'43"	75°55'27"
Well LN1665	400922075551101	40°09'22"	75°55'11"
Well LN1666	400926075543601	40°09'26"	75°54'36"
Well LN1678	400918075543901	40°09'18"	75°54'39"
Spring LN SP 59	400903075551501	40°09'03"	75°55'15"
Spring LN SP 60	400926075544501	40°09'26"	75°54'45"
PRECIPITATION	–	40°08'27"	75°58'50"

Station	Storet number	Latitude	Longitude
	COMPONENT 3 - FIELD SITES		
	Field-Site 1		
Surface Water			
Runoff Site No. 1	01576083	40°07'42"	75°58'40"
Groundwater			
Well LN 1643	400741075584301	40°07'41"	75°58'43"
Well LN 1644	400742075584301	40°07'42"	75°58'43"
Well LN 1645	400746075584301	40°07'46"	75°58'43"
Well LN 1646	400744075584701	40°07'44"	75°58'47"
Well LN 1647	400740075584901	40°07'40"	75°58'49"
Well LN 1648	400738075584601	40°07'38"	75°58'46"
Well LN 1649	400744075585401	40°07'44"	75°58'54"
Well LN 1650	400741075585101	40°07'41"	75°58'51"
Well LN 1651	400739075585101	40°07'39"	75°58'51"
Well LN 1652	400738075585301	40°07'38"	75°58'53"
Well LN 1653	400737075585601	40°07'37"	75°58'56"
Well LN 1659	400739075584501	40°07'39"	75°58'45"
Well LN 1660	400745075585301	40°07'45"	75°58'53"
Well LN 1661	400744075585601	40°07'44"	75°58'56"
Spring LN SP58	400744075583901	40°07'44"	75°58'39"
PRECIPITATION	–	40°07'41"	75°58'50"
	Field-Site 2		
Surface Water			
Runoff Site No.2	01576335	40°07'42"	75°58'40"
Groundwater			
Well LN 1667	401152076105501	40°11'52"	76°10'55"
Well LN 1669	401149076105501	40°11'49"	76°10'55"
Well LN 1670	401156076105701	40°11'56"	76°10'57"
Well LN 1671	401152076105801	40°11'52"	76°10'58"
Well LN 1672	401152076110501	40°11'52"	76°11'05"
Well LN 1673	401148076110301	40°11'48"	76°11'03"
Well LN 1674	401145076111501	40°11'45"	76°11'15"
Well LN 1675	401150076110701	40°11'50"	76°11'07"
Well LN 1676	401152076110101	40°11'52"	76°11'01"
Well LN 1677	401156076110501	40°11'56"	76°11'05"
Well LN 1679	401152076105701	40°11'52"	76°10'57"
Well LN 1680	401156076110901	40°11'56"	76°11'09"
Well LN 1681	401147076110801	40°11'47"	76°11'08"
Well LN 1682	401148076105901	40°11'48"	76°10'59"
Spring LN SP 61	401152076105301	40°11'52"	76°10'53"
PRECIPITATION	–	40°11'50"	76°10'53"

WATER-QUALITY REPORTS OF THE CONESTOGA RIVER HEADWATERS PROJECT

Reports completed and published:

Fishel, D.K., and Lietman, P.L., 1986, Occurrence of nitrate and herbicides in ground water in the upper Conestoga River basin, PA, USGS-WRI 85-4202

Gerhart, J.M., 1986, Ground-water recharge and its effect on nitrate concentration beneath a manured field site in PA, Ground Water journal, Vol. 24, No. 4

Chichester, D.C., 1987, Conestoga Headwaters RCWP in PA, USGS pamphlet

Fishel, D.K., and Lietman, P.L., 1988, Occurrence of nitrate and herbicides in ground water in the upper Conestoga River basin, PA, Proceedings: Agricultural Impacts on Ground Water - A Conference

Lietman, P.L., Gerhart, J.M., and Wetzel, K.L., 1989, Comparison of methods for sampling dissolved nitrogen in a fractured carbonate-rock aquifer, Ground Water Monitoring Review, Vol. IX, No. 1

Chichester, D.C., 1989, Evaluation of agricultural best-management practices in the Conestoga River headwaters, PA, USGS OFR 88-96

Lietman, P.L., and Hall, D.W., 1991, Herbicides in surface and ground water of agricultural, carbonate valleys, Lancaster County, PA, Proceedings of the Third National Research Conference on Pesticides, Virginia Polytechnic Institute

Report approved by U.S. Geological Survey headquarters and being prepared for publication:

Fishel, D.K., Brown, M.J., Kostelnik, K.M., and Howse, M.A., Description and water quality of the Little Conestoga Creek headwaters prior to the implementation of nutrient management, USGS WRI

Papers approved by the U.S. Geological Survey headquarters and being prepared for publication in The National RCWP Symposium Proceedings:

Lietman, P.L., 1992, Effects of pipe-outlet terracing on runoff water quality at an agricultural field site, Conestoga River Headwaters, Pennsylvania

Koerkle, E.H., 1992, Effects of nutrient management on surface-water quality of a small watershed, Conestoga River Headwaters, Pennsylvania

Hall, D.W., and Risser, D.W., 1992, Effects of nutrient management on nitrogen flux through a karst aquifer in the Conestoga River Headwaters basin, Pennsylvania

Journal articles accepted for publication in Journal of Ground Water, 1992, 1993:

Hall, D.W., Effects of pipe-outlet terracing on ground-water quantity near Churchtown, Pennsylvania

Hall, D.W., Effects of nutrient management on nitrate levels in ground-water near Ephrata, Pennsylvania

Reports in U.S. Geological Survey review and planned outlet:

Lietman, P.L., Hall, D.M., Langland, M.J., Chichester, D.C., and Ward, J.R., Characterization of surface-and ground-water quantity and quality of a small carbonate basin near Churchtown, PA, prior to implementation of terracing and nutrient management, USGS WRI

Koerkle, E.H., Hall, D.W., Risser, D.W., Lietman, P.L., and Chichester, D.C., Characterization of surface- and ground-water quantity and quality of a small carbonate basin near Ephrata, PA prior to implementation of nutrient management, USGS WRI

Hall, D.W. and Risser, D.W., An estimated nitrogen budget for a farm in Lancaster County, PA, journal article

Reports in draft by U.S. Geological Survey and planned outlet:

Lietman, P.L., Hall, D.W., and Gustafson-Minnich, L.G., Effects of terracing and nutrient management on surface- and ground-water quantity and quality in a small carbonate basin near Churchtown, PA, 1983-1989, USGS WRI

Koerkle, E.H., Brown, M.J., and Fishel, D.K., Effects on nutrient management on water quality of the Little Conestoga Creek basin, PA, 1984-1989, USGS WRI

Hall, D.W., Koerkle, E.H., and Lietman, P.L., Effects of nutrient management on surface- and ground-water quality in a small carbonate basin near Ephrata, PA, 1986-1990, USGS WRI

Lietman, P.L., Effects of agricultural best-management practices on surface- and ground-water quantity and quality in the Upper Conestoga River basin, PA, 1982-1990 - A summary report, USGS WSP

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